Research article

Clin Ter 2020; 171 (6):e490-500. doi: 10.7417/CT.2020.2263

Role of post mortem CT (PMCT) in high energy traumatic deaths

M. Di Paolo[1], A. Maiese[1], M. dell'Aquila[3,], C. Filomena[1], S. Turco[1], C. Giaconi[2], E. Turillazzi[1]

[1] Section of Legal Medicine- University of Pisa, S. Chiara Hospital, Pisa; [2] Department of Diagnostic and Interventional Radiology, Pisa; [3]Department of Anatomical, Histological, Forensic and Orthopaedic Sciences, Sapienza University of Rome, Italy

Abstract

Background. Post Mortem Computed Tomography (PMCT) is being increasingly implemented in forensic field and could be an adjuvant to classic autopsies. In this study we evaluated the feasibility of complementation of conventional autopsy in trauma victims with PMCT.

Materials and methods. A total of 21 subjects, who had sustained various types of blunt high-energy trauma, were selected from the casuistry of the Section of Legal Medicine at University of Pisa: before autopsy, a PMCT examination (Toshiba Aquilion 16 CT scanner) was performed, and after the acquisition of the raw images, MPR and VR reconstructions were performed with dedicated software.

Results. PMCT is more sensitive than conventional autopsy in detecting skeletal injuries, whilst autopsy constitutes the method of choice for the detection of thoracic and abdominal visceral injuries.

Conclusion. PMCT should be considered a useful tool in addition to conventional autopsy in evaluating trauma victims: it detects further bone fractures in body parts difficult to investigate during autopsy (i.e. posterior regions), facilitating the pathologist in the reconstruction of events and in determining the cause of death. ***Clin Ter 2020; 171 (6):e490-500. doi: 10.7417/CT.2020.2263***

Key words: *PMCT, Autopsy, Traumatic death, virtopsy*

Introduction

Currently, post – mortem imaging has become increasingly common for death investigation. Beyond the conventional radiography, which is the oldest imaging method used in forensic medicine, the application of modern cross-sectional imaging techniques, especially multidetector computed tomography (MDCT) and magnetic resonance imaging (MRI) (1, 2), for forensic death investigations has been introduced in forensic centers all over the world. The idea of using imaging tools in forensic investigation came to light/ came up/ emerged several decades ago and was followed by the concept of objective non-invasive documentation of body surface for forensic purposes. Post-mortem imaging has considerably evolved over the years and nowadays is a well-known and useful tool for forensic investigation (3). In the best forensic practice Post Mortem Computed Tomography (PMCT) and 3D reconstruction provide a powerful instrument in the evaluation of the causes and manner of death (4, 5), distinguishing between those findings related to traumas and those related to post mortal changes. For these reasons, post-mortem imaging has to be considered as an aid in the forensic investigations, rather than an alternative to conventional post-mortem procedures; providing improvements for the general workflow of post-mortem examinations (6, 7, 32).

Postmortem imaging adds value in many fields of forensic assessment of the cause of death: traumatic events (8) (9) (10), badly damaged, burned or decomposed bodies, gunshot incidents (11) (12), detection of foreign bodies (13). Further perspectives for the use of post mortem imaging, such as investigation of sudden cardiac death (14, 31), and vascular tree (15, 16, 17, 18, 29, 30), have been strongly implemented in recent years through the development of new methods such as CT-angiography.

In particular, post-mortem imaging in cases of trauma has been widely used ~~during~~ over the years and can detect a wide spectrum of injuries, thus being a very useful complementary tool to the autopsy (33, 34).

Trauma, that is defined as any physical force or agent that causes bodily harm (19) is a worldwide pandemic and one of the leading causes of death and disability. Statistical data claim that about 5.8 million people die following, or from traumatic events every year worldwide, which accounts for 10% of global mortality. According to the data published by the World Health Organization, traumatic deaths are increasing in frequency: they foresee that in 2030 traffic accident will be one of the most sizable cause of death. Trauma globally is the sixth leading cause of death and the fifth ranking cause of moderate and severe disability. One out of every 10 deaths is a result of trauma in both sexes. In those under 35 years of age, it is the first cause of death and disability (20).

In addition to the short and long-term impact on health, the psychosocial and economic consequences of the various forms of trauma, deaths resulting from "trauma" are some of the most common cases encountered by the practicing

Correspondence: Aniello Maiese, E-mail: aniellomaiese@msn.com

ISSN 1972-6007

forensic pathologists. However, in dealing with traumatic death, high standard of practice is necessary to answer the challenge posed by such investigation (21, 22, 23, 24). Pathology of trauma is a complex issue. Echoing Hirsch said: "*too many pathologists think that the pathology of trauma is simple. Such pathologists fall into one of the two groups: those who have not seen traumatic pathology and those who have not thought about what they have seen*" (19).

In particular, high – energy trauma (HET), generally associated with road traffic accidents, collisions, falls from a great height or crushing accidents, often results in heterogeneous, complex injury patterns with both organ and osseous injuries, including neurovascular structures. Generally, HET victims present with fracture, comminution, and displacement of several bones and extensive soft tissue damage or avulsive soft/hard tissue injuries. The extent of lesions caused by HET is directly related to the mechanism of injury and is highly variable (23, 24).

In the investigative approach in trauma related deaths, postmortem imaging has been increasingly integrated into forensic workflow, thereby permitting more objective diagnoses of injuries' patterns (25). PMCT is thought to perform better than autopsy in detecting craniofacial, cerebral, thoracic and osseous lesions and gas accumulation; however PMCT, in the absence of contrast administration, has a low sensitivity in detecting abdominal and vascular injuries. Injuries that are most frequently missed by PMCT are contusions or superficial lesions of solid organs, small soft tissue contusions, hematoma or emphysema, small brain contusions or hematoma, and vessel transections or lacerations. For these reasons, since the comprehensive review by Scholing et al (26), an ongoing debate still exists whether PMCT techniques can be alternative, complementary or even a substitute to conventional autopsy (27).

This case series compares the PMCT and autoptic findings of 21 subjects who died due to HEG, aiming to contribute in assessing the role of PMCT in trauma deaths.

Material and methods

Cases were selected from the casuistry of the Section of Legal Medicine, Department of Surgical, Medical and Molecular Pathology and Critical Area, University of Pisa, Italy. A total of 21 subjects (17 men and 4 women) who had sustained various types of blunt high-energy trauma were studied: 6 motor vehicle accidents, 7 airplane crashes; 8 falls from a height (accident, suicide and homicide). Typical penetrating injuries such as gunshot or stab wounds were excluded from the study. All the patients died immediately due to the severity of trauma, thus no cardiopulmonary resuscitation nor ventilation were performed.

For all subjects included in the study, autopsy was performed between 24 and 48h after death. To avoid the progression of transformative phenomena, bodies were kept in cold storage room (−5 °C) until autopsy. Before autopsy, cadavers were transferred to the Radiology Department wrapped in gunny bags for PMCT examination with Toshiba Aquilion 16 CT scanner was performed in all cases. The scan parameter were: 120 kV; 250 mAs; pitch 0.938; collimation 16 x 1 mm; reconstruction thickness of 1 mm; reconstruction interval of 1 mm and standard reconstruction algorithm. In all cases the study covered the entire body except for one case, in which the CT scan covered only the maxillofacial region. The acquired scans were rendered using the open source software OsiriX® on a MacOSX® device in order to obtain a 3D reconstruction of the body surfaces. The scanning parameters were maintained for all the cadavers. For each case, time and mechanism of injury and time of death were recorded. In all cases the radiological interpretation was performed by a radiologist and the forensic pathologists reviewed the post -mortem CT images together with the radiologist. The PMCT examinations were also read again after each autopsy. Finally, the results of the two techniques were compared. PMCT findings that were not found during autopsy were considered PMCT false positive.

Results

In particular, as regard as visceral traumatic lesions, most of them were undoubtedly detected by both techniques (autopsy and PMCT), such as those at cephalic extremity, thoracic organs (Fig. 1) and abdominal wall (Fig. 2).

On the other side, certain lesions were recognized only by macroscopic section, e.g.: multiple brain contusions/brain lacerations (cases 3;10;18); pericardium laceration (cases 13;15); subpleural hemorrhages (case 2); diaphragm contusion (case 7) and complete bladder rupture (cases 1;18).

Moreover, lesions seen only at PMCT were: pneumopericardium (case 11); pneumomediastinum (cases 8;9;15;17;18;19); ground glass parenchymal opacities in the lungs (cases 9;11); pneumothorax (cases 5;9;15;17;18;19;20;21); diaphragm laceration (case 19); pneumoperitoneum (cases 8;18).

Referring to skeletal fractures, we have collected the following data.

Skull fractures were found in 17 cases, of which 3 injuries were detected only with PMCT and 14 by both techniques. More fractures were localized only by PMCT in craniofacial area, in particular those ones involving mandible, nasal septum and maxillary bones.

Spine fractures occurred in 14 cases, of which 7 injuries were detected only during PMCT and 7 by both techniques (Fig. 3). Regarding atlas and axis fractures, PMCT appears to be superior in every case and the advantage of CT scans becomes visible especially with fractures of processes (both spinous and lateral) and for a more detailed description of vertebrae body fractures.

As long as regards pelvic bones fractures (analyzed together with the sacrum bone ones), those were found in 9 cases, of which 4 injuries were detected only during PMCT and 5 by both techniques. Even in these anatomic regions, PMCT provides more accurate information.

Clavicula and scapula fractures were present in 14 cases, of which 6 injuries were detected only during PMCT and 8 by both techniques (Fig. 4). The greater capacity of CT in recognizing scapula lesions is due to its deeper and posterior anatomic location.

Sternum fracture occurred in 10 cases, of which 3 injuries were detected only during autopsy, 1 only during PMCT and

Table 1. *Summarizes the various visceral lesions described in each case by the two techniques (PMCT and autopsy). Lesions were described and listed with regard to body regions and organs.*

Lesions	Region	Organ	Type of lesion	PMCT	Autopsy
Typical lesions	Cephalic extremity	Brain	Encephalon missing (1;19) Diffuse subdural hemorrhage (2) Subarachnoid hemorrage (3;10;14) Multiple brain contusions (3;10) Brain lacerations (18)	+ + + + -	+ + (9;13;20;21) + (7;9;17;20) + (20) +
	Thoracic organs		Diffuse organs lacerations (1) Subcutaneous emphysema (8) Irregular profile of vena cava (14) Haemothorax (14;15;17;18;19;20;21)	+ + + +	+ -(8); + 15 + (laceration) + (7;12); -(20)
		Heart	Multiple contusions (3) Pneumopericardium (11;15) Collapsed aortic arch (14;15) Aortic laceration (20) Heart rupture Pericardium laceration (13;15;18;19)	+ + + +; -(15;18;19) -	+ (11;13) -(11) + (14 multiple lacerations) + (1;15;18) + (1;18;19;21)
		Mediastinum	Pneumomediastinum (8;9;15;17;18;19)	+	-
		Lungs	Multiple parenchymal contusions (2;3;4;5;12;14;15) Parenchymal lacerations (5;12;14;15;17;20) Hyperdensity in trachea and bronchi (2;3;9) Ground glass parenchymal opacities (9;11)	+; -(18) + +; -(18) +	+ (1;7;9;13;17;18;21) + (7); -(20) + (blood) (18;19); -(20) -
		Pleura	Pneumothorax (5;9;15;17;18;19;20;21) Pleural effusion (9;13) Subpleural haemorragies (2)	+ + -	- + +
		Thoracic wall	Burnt body surface (1;4) Subcutaneous emphysema (5;9;12;15;17;18)	+ +	+ +
		Diaphragm	Laceration (19) Contusion (7)	+ -	- +
	Abdomen		Subcutaneous emphysema (8;12;15) Pneumoperitoneum (8;18) Haemoperitoneum (5;8;9;13;14;17;21) Diffuse organs lacerations (1)	+ + + +	-(8;12); + (15) - + (19); - (9) +
		Liver	Lacerations (2;4;5;8;10;12)	+	+ (1;5;7;14;15;18;19)
		Spleen	Lacerations (8;14;15)	+	+ (1;7;19)
		Kidneys	Laceration (4;14)	+	+ (5;7;13;17;18;19;20)
		Bladder	Complete rupture (1;18)	-	+

Table 2. Summarizes skeletal fractures described in each case by the two techniques (PMCT and autopsy).

Case	Mechanism of injury	Radiological findings	Autoptic findings
1. Male (30 y)	Airplane crash (passenger)	Skeletal fractures: • Complete skull destruction • Maxillofacial comminuted fractures • Detachment of the lower limb from the torso • Clavicle comminuted fracture • Multiple comminuted ribs fractures • Right ulna displaced fracture at its middle third • D12 body section • Pelvis bones multiple and comminuted fractures, involving right coxo - femoral joint • Right femur displaced fracture at its distal third	External examination: • Skull complete destruction (encephalon missing) • Maxillofacial comminuted fractures • Spine and ribs multiple fractures • Evisceration • Detachment of the lower limb from the torso Skeletal fractures at autopsy: • Clavicle comminuted fracture • Fractures ribs: left III-VII on the lateral arch, VIII-XI on the posterior arch, displaced; right II-III on the posterior arch, IV- V on the lateral arch, displaced • Right ulna displaced fracture at its middle third • D12 body section • Multiple and comminuted fractures of pelvic bone, involving right coxo-femoral joint • Right femur fracture at its distal third
2. Male (28 y)	Airplane crash (pilot)	Skeletal fractures: • Left maxillary bone fracture • Right shoulder fracture • Sternum fracture • Displaced ribs fractures VI-VIII on the lateral arch on the right, VI-VII on the anterior arch, on the left; • L1 fracture • Right fibula fracture	External examination: • Full thickness scalp discontinuation in the right parietal region with exposure of the underlying theca Skeletal fractures at autopsy: • Left maxillary bone fracture • Sternum complete fracture • Ribs fractures: right - IV-VII on the posterior arch; left - IV-VI on the anterior arch, III-VIII on the lateral arch • Right shoulder fracture • L1 body fracture • Right fibula fracture
3. Male (40 yo)	Airplane crash (pilot)	Skeletal fractures: • Anterior cranial fossa fracture • Multiple ribs fractures on the left side • L1 and L4 body fractures and L3 and L4 transverse processes fractures • Left ulna and radius complete fracture at their middle third • Displaced right femur fracture • Displaced left tibia and fibula fracture	External examination: • Abnormal motility of femur (at its distal third) Skeletal fractures at autopsy: • Anterior cranial fossa fracture • VI-IX ribs on the posterior arch non-displaced fractures on the left side • Left ulna and radius complete fracture at their middle third • Right femur fracture • Left tibia and fibula fracture
4. Male (44 yo)	Airplane crash (passenger)	Skeletal fractures: • Mandible fracture on the left side • Sternal body fracture • Left shoulder fracture • Multiple ribs fractures on the left side • L4-L5 body fracture • Left fibula fracture	External examination: no findings suggestive for fractures Skeletal fractures at autopsy: • Sternal body fracture • Multiple ribs fractures on the left side
5. Female (16 yo)	Pedestrian-car accident: pedestrian run over by a car	Skeletal fractures: • Multiple displaced ribs fractures: right IV-VIII on the postero-lateral arch; left I-II on the posterior arch	External examination: no findings suggestive for fractures Skeletal fractures at autopsy: • Ribs fractures: right - II-III on the anterior arch, IV- VIII on the lateral arch, IV-VIII on the posterior arch; on the left - I-II on the posterior arch
6. Male (70 yo)	Fall from height (2 mt)	Skeletal fractures: • Double fracture of the anterior arch (left and right side) of the atlas extending to left lateral mass (comminuted fractures)	External examination: no findings suggestive for fractures Skeletal fractures at autopsy: negative
7. Male (44 yo)	Fall from high height (8 mt)	Skeletal fractures: • Theca fracture involving frontal, parietal, temporal and, most of all, occipital bones • Middle and posterior cranial fossae fracture • Sternum fracture • Scapula bilateral displaced fractures • Bilateral fractures of all the ribs on the posterior arch • C3, C4, D7, D8, D11, D12, L1 body non-displaced fractures • L5 spinous process fracture • Sacrum fracture • Pelvis: Right superior pubic ramus fracture, bilateral inferior pubic rami fracture, left iliac crest fracture • Left femoral neck fracture • Right femoral neck displaced fracture	External examination: • Theca open fractures • Thorax depression (more evident on right side) due to multiple ribs fractures • Dorso-lumbar spinous processes multiple fractures • Findings suggestive for displaced bilateral fracture of pelvis bones Skeletal fractures at autopsy: • Theca fractures: frontal, parietal, temporal (with petrous parts fractures) and, most of all, occipital bones • Middle and posterior cranial fossae fracture • Sternum fracture • Ribs fractures: right - III-IV on the anterior arch, displaced, I-XII on the posterior arch; left - I-XII on the posterior arch • D7, D8, D11 body non-displaced fractures

follows

8. Female (45 yo)	Motorcycle accident	Skeletal fractures: • Nasal septum fracture • Right scapula body wedge shaped fracture • Right III and IV ribs non-displaced fracture	External examination: no findings suggestive for fractures Skeletal fractures at autopsy: • Right scapula fracture • Ribs fractures: right III-IV on the anterior arch, displaced; left VII on the anterior arch
9. Male (22 yo)	Car accident (driver)	Skeletal fractures: • Mandible displaced comminuted fracture • C2 body fracture	External examination: • laryngeal cartilage and bone structures fracture with leakage of hematic material at mouth opening Skeletal fractures at autopsy: • Mandible displaced comminuted fracture • C2 body fracture
10. Male (42 yo)	Car – motorcycle accident (motorcycle driver)	Skeletal fractures: • Cranial base multiple comminuted fracture, ring fracture around foramen magnum with comminuted fracture of parietal bone and the posterior part of both occipital bones • Bilateral clavicle fracture • Bilateral scapula fracture • Displaced fracture of I-III ribs on the postero-lateral arch on the right side; displaced fracture of I-IV on the anterior arch on the left side	External examination: • Left otorrhagia; on touching of the head, abnormal motility due to theca multiple fractures Skeletal fractures at autopsy: • Parietal bone and posterior part of both occipital bones comminuted fractures • Transverse fracture involving both middle cranial fossae • Ring fracture around foramen magnum • Bilateral clavicle fracture • Ribs fractures: right I-III bifocal fracture on the anterior and posterior arches, IV-V on the posterior arch; left I-IV on the lateral arch
11. Male (28 yo)	Swimming in the sea (distance from the water surface 40/50 cm)	Skeletal fractures: • Atlas posterior arch fracture • Fracture of the axis dens, of its antero-inferior part and right transverse foramen • First left rib fracture	External examination: no findings suggestive for fractures Skeletal fractures at autopsy: • Sternum displaced fracture between II-III intercostal space • Ribs fractures: right I and IV on the anterior arch, I-III and V-X on the lateral arch; left III on the anterior arch
12. Male (23 yo)	Fall from high height (7 mt)	Skeletal fractures: • Right maxillary bone non-displaced fracture • Sternal manubrium fracture • Left clavicle fracture and right clavicle probable fracture • Right olecranon fracture • Right scapula multiple fractures • Bilateral ribs fractures: right - II-VII, left - III-XI • Right wing of ilium fracture and inferior pubic ramus bilateral fracture	External examination: • Bilateral thorax depression, due to multiple ribs fractures Skeletal fractures at autopsy: • Maxillary bone fracture • Sternal manubrium fracture • Ribs fractures: right I-II on the posterior arch, III-X on the lateral arch; left - I on the paravertebral line, II-XI on the lateral arch.
13. Female (82 yo)	Fall from high height (5 mt)	Skeletal fractures: • Right zygomatic, nasal and right maxillary bones fractures • Distal third of sternal body non-displaced fracture • Ribs fractures of V, VI, VII, VIII, XI and XII on the right side and of III, IV, V on the left side • Right transverse processes of all lumbar vertebrae fractures • Right wing of ilium and both superior and inferior pubic rami non-displaced fractures •Left radius displaced and partially impacted fracture • Displaced fracture with tibial plateau depression on both side • Right fibula's head displaced comminuted fracture • Tibia and fibula right distal epiphysis displaced comminuted fracture •Right calcaneus non-displaced fracture	External examination: • On touching of nasal bone, noises and preternatural mobility suggestive for fracture • On touching of thorax abnormal softness, due to multiple ribs fractures • At mobilization noises suggestive for fractures at right scapula-humeral joint • At mobilization left wrist preternatural mobility • Right lower limb dysmorphic, shortened and externally roted • Right lower limb distal third preternatural mobility suggestive for displaced bi-bones fracture • Right ankle lateral malleolus preternatural mobility suggestive for displaced fracture Skeletal fractures at autopsy: • Ribs fractures: right - III, IV-IX on the anterior arch; V-IX also on the posterior arch; X on the posterior arch; left - III-VI on the anterior and posterior arch; IX-X on the anterior arch • Middle third of sternal body and xiphoid process fracture • Superior and inferior pubic rami non-displaced fractures
14. Male (68 yo)	Car – motorcycle accident (motorcycle driver).	Skeletal fractures: • Axis' dens fracture and avulsion • Sphenoidal bone, zygomatic arch and lateral wall of the left orbit bilateral fractures • C5-C6 dislocation • C6 spinous process fracture • Displaced fractures of IV at the antero-lateral portion and VI-X at the posterior portion, on the right; XII rib posterior portion and I rib anterior portion fractures, on the left • Comminuted fracture of L1 superior surface • Left fibula distal third and left tibia epiphysis displaced comminuted fracture; right tibia and fibula distal metaphysis displaced fracture; right tibia distal epiphysis non-displaced fracture • Left wing of ilium, left inferior pubic ramus, pubic symphysis and left acetabulum displaced comminuted fracture	External examination: • Leakage of hematic material from mouth and nasal orifices • Cervical spinal column and rib cage preternatural mobility due to multiple ribs fractures • Both inferior limbs dysmorphic, due to tibia and fibula distal third displaced fractures Skeletal fractures at autopsy: • Atlas-axis joint fracture-dislocation, with avulsion of axis' dens • Ribs fractures: right - III-V on the anterior arch; VIII-IX on the lateral arch; left - I-VII on the posterior arch • Tibia and fibula displaced fractures on both sides • Left pelvis bone fractures

follows

15. Male (69 yo)	Pedal cyclist – motor vehicle accident (cyclist).	Skeletal fractures: • Right clavicula and both scapulae displaced fractures • Multiple displaced fracture of all ribs on the right, on the postero-lateral arch, and fractures of I-IX on the left • Right L1-L3 transverse processes fractures	External examination: • Cervico-thoracic-abdominal subcutaneous emphysema Skeletal fractures at autopsy: • Right clavicle and bilateral scapular fractures • Ribs: right - I-XII on the posterior arch displaced comminuted fractures; left - I-III and V-VIII on the lateral line displaced fractures, IV and IX on the lateral arch fracture
16. Female (21 yo)	Fall from high height (20-25 mt)	Skeletal fractures: • Mandible left part comminuted fracture • Neurocranial and facial bones comminuted fractures • Left scapula acromion comminuted fracture and left scapula glenoid cavity antero-inferior edge fracture • Ribs fractures: right - IV-V on the posterior arch undisplaced fractures; left - I-V on the posterior arch displaced fractures • Right humerus distal epiphysis comminuted fracture • D6 body fracture; D4, D5, D6 e D7 left transverse processes fracture • Left wing of ilium displaced fracture with diastasis • Superior and inferior pubic rami bilateral fractures	External examination: no findings suggestive for fractures Skeletal fractures at autopsy: • Facial bones multiple fractures • Mandible multiple fractures with dislocation • Frontal bone fracture with diastasis and both parietal bones fracture • Anterior and middle cranial fossae transverse bilateral fracture • Ribs fractures: right - VI on the anterior arch
17. Male (29 yo)	Fall from high height (10 mt)	Skeletal fractures: • Cranial base fracture on left side • Bilateral fracture of maxillary bone • Left ygomatic process fracture • Nasal bones fracture • Both scapulae fractures • Multiple left ribs fracture on the posterior arch • Multiple left lumbar vertebrae transverse processes fractures • Displaced, comminuted fractures of all pelvis bones • Left elbow articular, displaced, comminuted fracture • Right tibia middle third non-displaced fracture	External examination: • Leakage of hematic material from mouth and nasal orifice • Left thorax preternatural depression • Pelvis preternatural mobility • Right inferior limb shortened and extra-rotated Skeletal fractures at autopsy: • Nasal bones fractures • Sella turcica lateral wall fracture • Ribs fracture on the left side: V-VII on the anterior arch, VI and VII on the lateral arch; I-V on the posterior arch • Open fracture of the left elbow • Right hand, carpal and metacarpal bones fractures
18. Male (37 yo)	Plane crash (pilot)	Skeletal fractures: • Skull complete destruction • Mandible displaced comminuted fracture • Hyoid displaced fracture with detachment of the right lateral part • Left clavicle displaced fracture • Left scapular fracture • Multiple bilateral displaced fractures of all ribs • Manubrium-sternal joint fracture with diastasis • Bilateral multiple transverse processes of all the dorso-lumbar vertebrae fractures • Fracture of all pelvis bones with bilateral dislocation of coxo-femoral joint	External examination: • Nasal bone flattening • On touching theca abnormal softness suggestive for fracture • Thorax asymmetry and deformity suggestive for fracture • Left upper limb, middle third, forearm dysmorphic suggestive for fracture • Both inferior limb, proximal third, open fractures Skeletal fractures at autopsy: • Multiple fractures of theca • Multiple fractures of cranial base • Sternal body, third middle, fracture • Fracture of all ribs on the anterior arch on both side; fractures of III left rib and right II-III ribs on the lateral arch
19. Male (28 yo)	Plane crash (pilot)	Skeletal fractures: • Skull complete destruction • Axis' dens fracture • Mandible non-displaced fracture • Cervical vertebrae posterior arch fracture • Multiple displaced bilateral ribs fractures • Sternal manubrium displaced fracture • Both scapulae fracture • Right vertebral transverse processes multiple fracture • Right wing of ilium displaced fracture with diastasis • Right femoral neck fracture with dislocation of the coxo-femoral joint	External examination: • Skull complete destruction (encephalon missing) • Asymmetric thorax depression due to multiple ribs fractures • Fracture of the pelvis bones Skeletal fractures at autopsy: • Bilateral clavicle fracture • Multiple ribs fractures on the anterior arch • Right humerus, superior third, open fracture; forearm, distal third fracture • Right femur fracture; right leg fracture at its middle third • Left leg distal third, open fracture
20. Male (27 yo)	Plane crash (co-pilot)	Skeletal fractures: • Comminuted fracture of cranial base involving also left maxillary sinus posterior wall • Frontal, occipital and parietal bones multiple fractures on both sides • Atlas, right part, probably non- displaced fracture • Right scapula displaced comminuted fracture • Left clavicle, middle third, displaced fracture • Multiple fractures of the spinous and transverse processes of dorso-lumbar vertebrae • D11-D12 pedicles complete fracture with complete posterior dislocation of the vertebral column.	External examination: • Abnormal thorax depression due to multiple ribs fractures Skeletal fractures at autopsy: • Occipito-parietal bones multiple fractures on both sides • Anterior middle and posterior fossae multiple fractures • Sternal body fracture • Bilateral fracture of X-XII ribs on the posterior arch • Displaced myelic fracture of D12 body with complete detachment between dorsal and lumbar spine

follows

21. Male (25 yo)	Precipitation (9 mt)	Skeletal fractures: • Left mastoid process, right frontal bone, bilateral parietal and occipital bones multiple fractures • Right sphenoidal and maxillary bones fractures • Right scapula body and acromion displaced fracture • Right clavicula non- displaced fracture at its middle third • D10 burst fracture • D11 anterior wall fracture • D12 transverse process fracture • L1 burst fracture with stenosis of the spinal canal • L2 right transverse process fracture • Ribs fractures: right - II, III, V, VI, VII, XI on the posterior arch; II-VIII on the antero-lateral arch; left - probable fracture of anterior arch of II and IV; V-VII on the antero-lateral arch; VIII-X on the lateral arch.	External examination: • On touching theca depression • Abnormal thorax depression due to multiple ribs fractures • Abnormal motility at the handling of both superior upper limbs probably due to bilateral scapular fractures Skeletal fractures at autopsy: • Ribs fractures: right - I-VII on the posterior arch; II-X also on the anterior arch; XI-XII on the posterior arch; left – II-VII on the anterior arch; VII-X on the lateral arch • Sternal body fracture • D10-L2 fractures

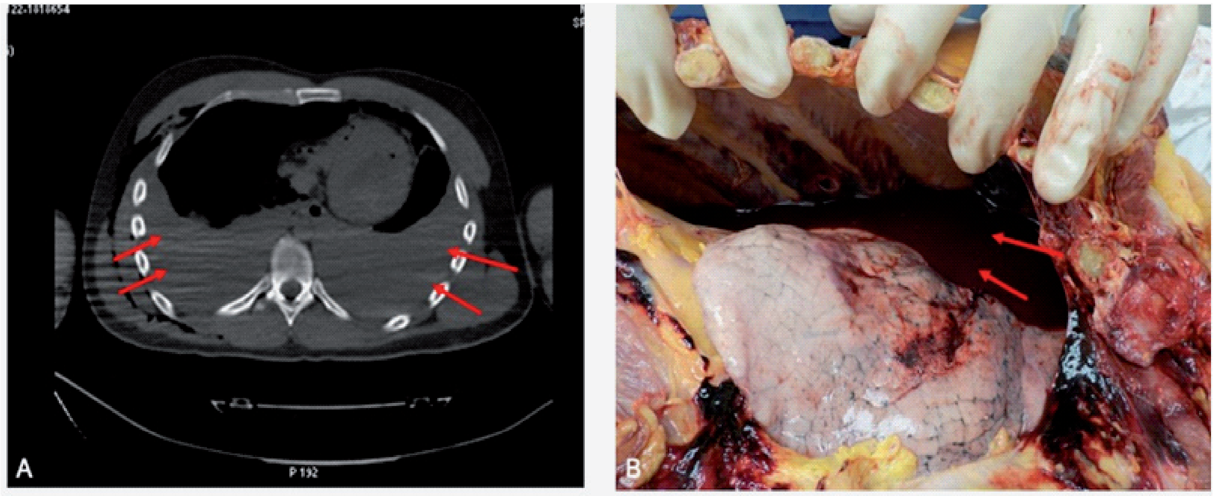

Fig. 1. A) Axial computed tomography (CT) scans: bilateral Massive hemothorax (red arrows) with ribs fracture in a case of car accident. B) Autopsy examination. The presence of the bilateral massive hemothorax (red arrows) and ribs fracture the PMCT findings confirmed

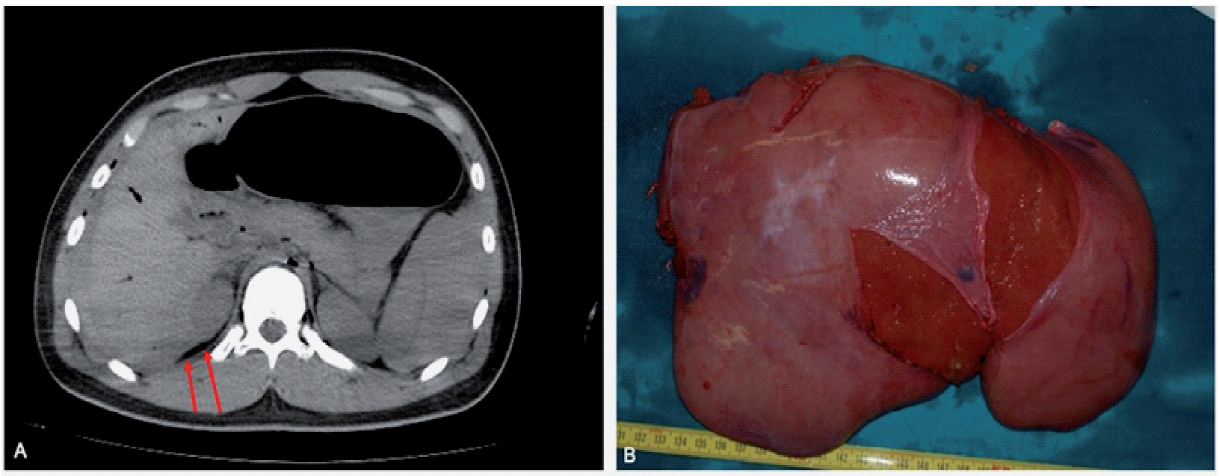

Fig. 2. A) Axial computed tomography (CT) scans: irregular hepatic shape (red arrows) with uneven structure for hepatic rupture consequent a car accident. B) Autopsy photograph: view of the liver lacerations.

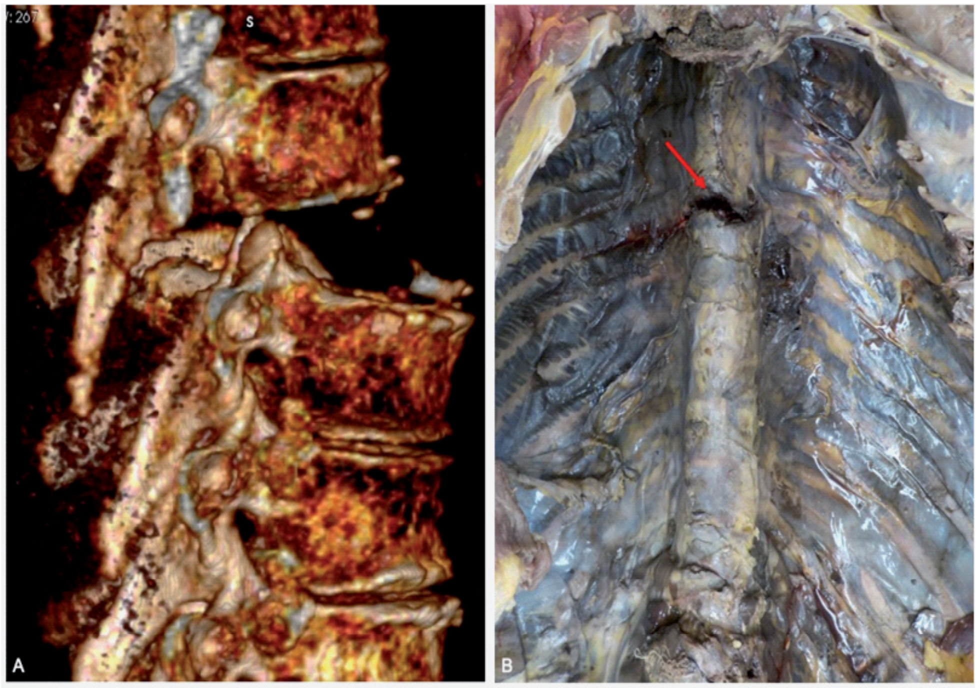

Fig. 3. (A) 3D-VRT (Volume Rendering Technique) of the CT data and Autopsy examination (B): D7 anterolisthesis with bilateral isthmic lysis and loss of normal joint relations with D6.

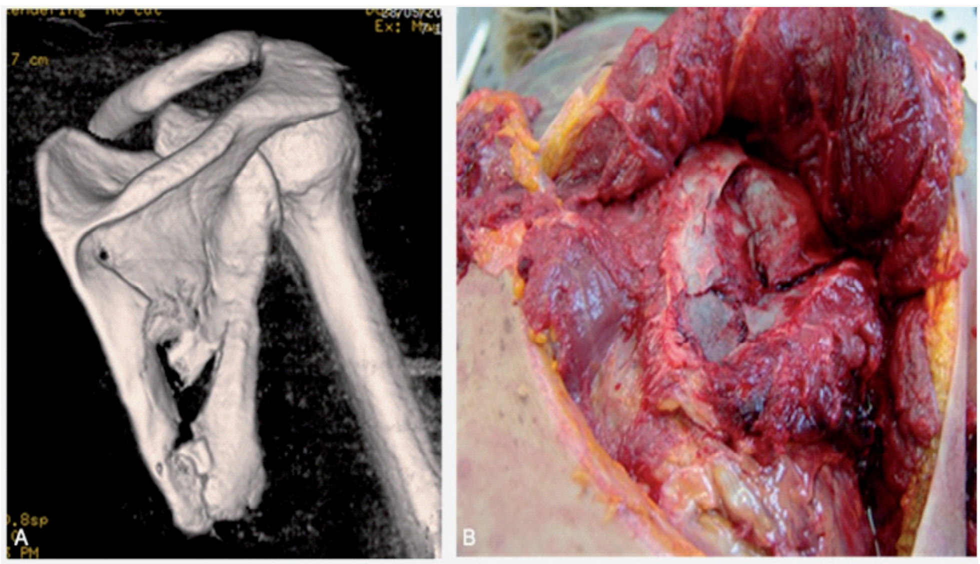

Fig. 4. 3D-VRT (Volume Rendering Technique) of the CT data (A) and autopsy examination (B) posterior view of the scapular fracture in a case of motorcycle accident.

6 by both techniques. In 2 cases, the observation regarding the localization of the fracture was not consistent.

As for the trunk, rib fractures occurred in 19 cases, of which 18 detected by both techniques (Fig. 5), and in one case seen only at the autoptic table. It has emerged that autopsy provides a more detailed localization and at least in 3 cases there were significant discrepancies between autoptic and radiologic findings.

Humerus fractures were present in 3 cases, of which 2 injuries were detected only during PMCT and 1 by both techniques. The added value of CT consists of superior capacity of distinguish between humerus head dislocation or a frank fracture.

As for forearm bones (radius and ulna), fractures occurred in 4 cases, of which 1 injury was detected only during PMCT and 3 with both techniques. Hardly during an autopsy it's possible to clarify the presence of closed and undisplaced fractures, without pathological mobility, best evaluated by CT scan.

As for lower extremities, femur was broken in 6 cases, all detected with both techniques; lower leg bones fractures (tibia and fibula) were present in 7 cases, of which 1 injury was detected only during autopsy, 2 only during CT and 4 by both techniques (Fig. 6). The higher number of fractures reported in the PMCT referred to epiphysis regions. Especially for lower limbs bones the significant difference is due

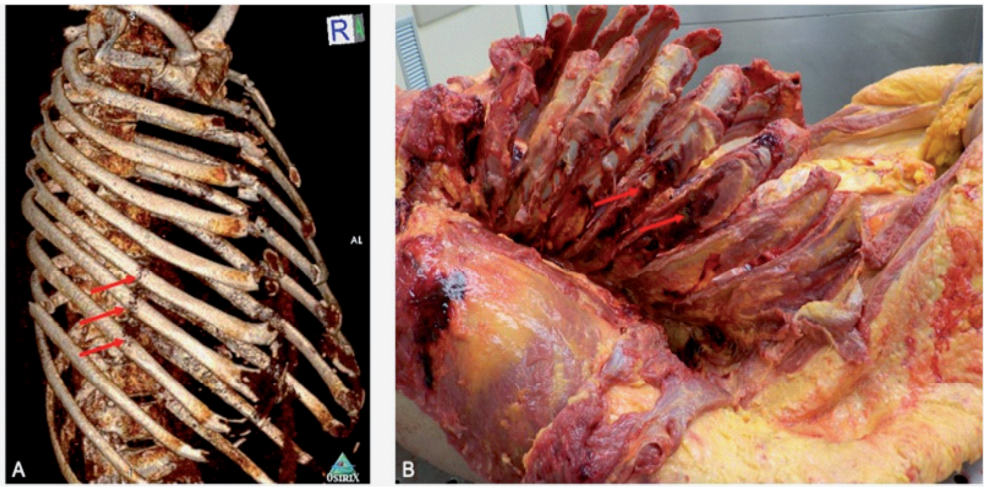

Fig. 5. Right thorax multiple rib fractures (red arrows). A) 3D-VRT (Volume Rendering Technique) of the CT data. B) Autopsy examination

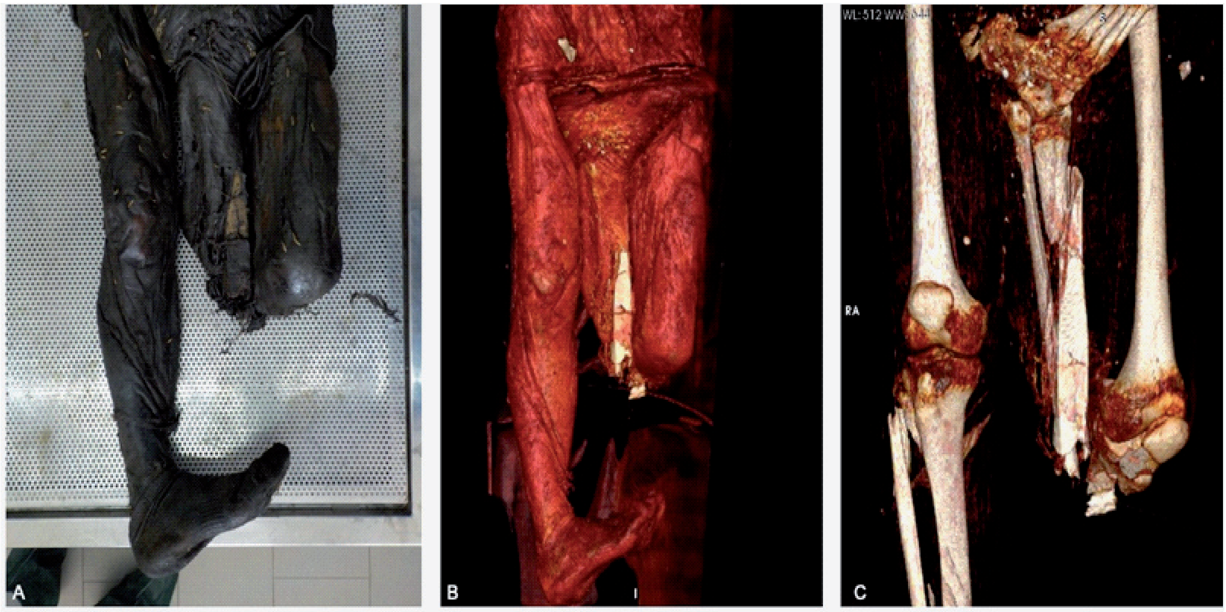

Fig. 6. (A) External examination and (B) 3D-VRT (Volume Rendering Technique) of the CT data: view of the body with dislocation of the left leg. (C) 3D-VRT: comminuted fracture of tibia and fibula.

to the fact that usually the autopsy of these regions is limited only to external examination.

Discussion

PMCT (postmortem computer tomography) is a well – established technique and it is considered to be the most important imaging modality in forensic and postmortem radiology, because it has several facilities: the equipment is widely available; the acquisition time of the images is extremely low and the pictures are easier to interpret.

For these reasons the use of PMCT is increasing in forensic medicine institutes, whereas the number of autopsies has fallen over recent years.

PMCT usefulness has been evaluated in specific cases, among which trauma deaths have been recently reviewed by Jalazadeh et al (27), who conclude that PMCT is an useful supplement to conventional autopsy in trauma victims.

However, most often autopsies were performed in places where equipped establishments are lacking and there is not CT scan availability. Other times, there are logistical and organizational difficulties depending on the limited compliance of radiologists, who have to deal with this particular issue only occasionally (26, 28).

According to our results and those found in the literature, the two techniques (PMCT and autopsy) complement each other: postmortem computed tomography is very useful for two or three-dimensional documentation and analysis of fractures, pathologic gas collections (air embolism, subcutaneous emphysema after trauma, hyperbaric trauma, decomposition effects), whilst autopsy documents better the various visceral lesions.

In our particular case, the lesions typically found following a HEG trauma are well documented (Table 1 and Table 2); they usually result from deceleration mechanisms.

All the typical lesions were diagnosed by the two techniques, PMCT and autopsy; nevertheless, there were some peculiar distinctions: PMCT detected better skeletal fractures, especially those involving scapula, due to its deeper and posterior anatomic location, difficult to investigate during autopsy, and rib fractures.

Sternum fracture occurred in 10 cases, of which 3 injuries were detected only during autopsy, 1 only during PMCT and 6 by both techniques.

There are many validation studies about post mortem imaging as a diagnostic tool, one of them, written by English pathologists and radiologists, and published on Lancet 2012 (28), compare CT, MRI and autopsies. This study highlights that CT is an accurate tool to make post mortem diagnosis, even more than MRI, and it can provide a confident cause of death, even if a not insignificant percentage of error remains (similar to that for clinical death certificates).

In view of the above considerations, the intent to deem CT as an autonomous tool in postmortem diagnostic, has to be revised.

Conclusion

In conclusion, PMCT is a widely available, fast and not expensive method useful to detect traumatic injuries. In cases of trauma deaths PMCT clearly detects a wide spectrum of skeletal injuries, with specific regard to craniofacial and thoracic (ribs, shoulder, vertebral) ones, frequently overseen during conventional autopsy.

Autopsy unquestionably constitutes the method of choice for the detection of thoracic and abdominal organ injuries. In our experience, PMCT proves to be a sensitive tool for detection and classification of skeletal injuries in high energy traumatic deaths and it could be used as a triage tool to select particular body parts.

Although a review of the literature does not support PMCT use as non-invasive replacement of autopsy, the increasing collective experience with PMCT and the collaboration between radiologists and medical examiners appears to be of great usefulness in the reconstruction of the course of events and in determining the cause of death. For all the reasons outlined above, we recommend PMCT implementation in forensic practice.

References

1. Grabherr S, Grimm J, Baumann P, Mangin P. Application of contrast media in post mortem imaging (CT and MRI). Radiol Med. 2015;120:824-34
2. Guidi B, Aquaro GD, Gesi M, et al. Postmortem cardiac magnetic resonance in sudden cardiac death. Heart Fail Rev. 2018;23:651-665
3. Bolliger SA, Thali MJ. Imaging and virtual autopsy: looking back and forward. Philos Trans R Soc Lond B Biol Sci. 2015; 370:1674
4. Gitto L, Serinelli S, Busardò FP, et al. Can post-mortem computed tomography be considered an alternative for autopsy in deaths due to hemopericardium? J Geriatr Cardiol. 2014; 11:363-367
5. Maiese A, Gitto L, dell'Aquila M, et al. When the hidden features become evident: the usefulness of PMCT in a strangulation-related death. Leg Med (Tokyo). 2014; 16:364-366
6. Lundström C, Persson A, Ross S, et al. State-of-the-art of visualization in post-mortem imaging. APMIS. 2012;120:316-26
7. Gitto L, Bonaccorso L, Maiese A, et al. A scream from the past: a multidisciplinary approach in a concealment of a corpse found mummified. J Forensic Leg Med. 2015; 32:53-58
8. Daly B, Abboud S, Ali Z, et al. Comparison of whole-body post mortem 3D CT and autopsy evaluation in accidental blunt force traumatic death using the abbreviated injury scale classification. Forensic Sci Int. 2013; 225:20-26
9. Maiese A, Serinelli S, Gitto L, et al. The usefulness of post-mortem computed tomography in a crush asphyxia. An excessive enjoyed rave party resulting in a fatal sleep! Journal of Forensic Radiology and Imaging. 2015; 3:91-95
10. Zerbo S, Di Piazza A, Lo Re G, et al. Utility of post mortem computed tomography in clivus fracture diagnosis. Case illustration and literature review. Leg Med (Tokyo). 2018;30:42-45
11. Maiese A, Gitto L, De Matteis A, et al. Post mortem computed tomography: useful or unnecessary in gunshot wounds deaths? Two case reports. Leg Med (Tokyo). 2014; 16:357-363
12. Arunkumar P, Maiese A, Bolino G, Gitto L. Determined to Die! Ability to Act Following Multiple Self-inflicted Gunshot Wounds to the Head. The Cook County Office of Medical Examiner Experience (2005-2012) and Review of Literature. J Forensic Sci. 2015;60:1373-9
13. Grabherr S, Baumann P, Minoiu C, et al. Post-mortem imaging in forensic investigations: current utility, limitations, and ongoing developments. Research and Reports in Forensic Medical Science. 2016; 6:25-37
14. Michaud K, Grabherr S, Jackowski C,et al. Post mortem imaging of sudden cardiac death. Int J legal med. 2014; 128:127-37
15. Renard Y, Hossu G, Chen B, et al. A guide for effective anatomical vascularization studies: useful ex vivo methods for both CT and MRI imaging before dissection. J Anat. 2018; 232:15-25
16. Turillazzi E, Frati P, Pascale N, Pomara C, Grilli G, Viola RV, Fineschi V. Multi-phase post-mortem CT- angiography: a pathological correlation study on cardiovascular sudden death. J Geriatr Cardiol. 2016;13:855-865
17. Shokry DA, Hussein MN, Hassan FM, et al. Diagnostic value of multiphase postmortem computed tomography angiography in selected cases of blunt traumatic death. Leg Med (Tokyo). 2018; 34:1-6
18. O'Donnel C, Lynch M, Woodford N. Can post-mortem CT and Angiography provide all the answers? Lancet. 2017; 390:646-647
19. Shkrum MJ, Ramsay DA. Forensic Pathology of Trauma. Totowa, Humana Press, 2007
20. Alberdi F, García I, Atutxa L, et al. Epidemiology of severe trauma. Med Intensiva. 2014; 38:580-588
21. Saukko P, Knight B. Knight's Forensic Pathology (Third Edition). CRC Press, Boca Raton, 2004, pp. 281-300
22. Di Maio DJ, Di Maio VJM, Forensic Pathology. CRC Press, Boca Raton, 1989; 253-282;285-288

23. Hunt JP, Weintraub SL, Marr AB. Kinematics of trauma. In: Feliciano DV, Mattox KL, Moore EE. Trauma (6 th ed). McGraw Hill, New York, Chapter 2008; 17:105-117
24. Burke MP, Forensic Pathology of Fractures and Mechanisms of Injury: Postmortem CT Scanning. Boca Raton, CRC Press, 2016
25. Panda A, Kumar A, Gamanagatti S, et al. Virtopsy Computed Tomography in Trauma: Normal Postmortem Changes and Pathologic Spectrum of Findings, Curr Problems Diagnost Radiol. 2015; 44:391-406
26. Scholing M, Saltzherr TP, Fung Kon Jin PHP, et al. The value of postmortem computed tomography as an alternative for autopsy in trauma victims: a systematic review. Eur Radiol. 2009; 19:2333–2341
27. Jalalzadeh H, Giannakopoulos GF, Berger FH, Fronczek J, van de Goot FRW, Reijnders UJ, Zuidema WP. Post-mortem imaging compared with autopsy in trauma victims-A systematic review. Forensic Sci Int. 2015;257:29-48
28. Roberts IS, Benamore RE, Benbow EW,et al. Post-mortem imaging as an alternative to autopsy in the diagnosis of adult deaths: a validation study. Lancet. 2012; 379:136-142
29. Grabherr S, Heinemann A, Vogel H, et al. Postmortem CT angiography compared with autopsy: a forensic multicenter study. Radiology. 2018; 288:270-276
30. Rutty, GN, Morgan, B, Robinson, C, et al. Diagnostic accuracy of post-mortem CT with targeted coronary angiography versus autopsy for coroner-requested post-mortem investigations: a prospective, masked, comparison study. Lancet. 2017; 390:145-154
31. Michaud K, Genet P, Sabatasso S, et al. Postmortem imaging as a complementary tool for the investigation of cardiac death. Forensic Sci Res. 2019; 4(3):211-222
32. Gascho D, Thali MJ, Niemann T. Post-mortem computed tomography: technical principles and recommended parameter settings for high-resolution imaging. Med Sci Law. 2018; 5 8:70–82
33. Willaume T, Farrugia A, Marie KE, et al. The benefits and pitfalls of post-mortem computed tomography in forensic external examination: a retrospective study of 145 cases. Forensic Sci Int. 2018;286:70-80
34. Christe A, Flach P, Ross S, et al. Clinical radiology and postmortem imaging (Virtopsy) are not the same: specific and unspecific postmortem signs. Leg Med (Tokyo). 2010; 12:215–222