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Comparative study of postmortem computed tomography (PMCT) against traditional forensic autopsy findings in fatal road traffic accidents — a pilot analysis

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Abstract

Background Virtopsy is "a virtual alternative to the traditional autopsy, conducted with scanning and imaging technology," mainly with the use of postmortem computed tomography (PMCT). It is still in the budding stage in India. The Department of Forensic Medicine and Toxicology, All India Institute of Medical Science, New Delhi, is the first center in the country that has established a facility for virtual autopsy. This facility aims to supplement the traditional autopsy findings and also to replace/curtail internal dissection in autopsy in the future, for which there has always been an aversion in relatives of the deceased due to emotional and religious reasons. The PMCT being a noninvasive, preservative, and objective procedure would be preferred by relatives than traditional autopsy. So, in this regard, this pilot study was conducted with the objective for comparison of PMCT vs traditional autopsy findings in fatal road traffic accidents to analyze its advantages and limitations in order to replace/augment the traditional autopsy with PMCT in the near future in road traffic accident cases.

Results The authors evaluated 10 cases of road traffic accident victims. In each case, an autopsy was preceded by a PMCT examination using a 16-slice Multi-Slice CT spiral scanner. The fractures of the skull, facial bones, clavicle, scapula, and vertebra were located more precisely as compared to traditional autopsy. Interpretation of the ventricular hemorrhages of the brain is much better in PMCT. PMCT should be the investigation of choice for pneumothorax, pneumoperitoneum, pneumocephalus, and hemosiuns, while it needs further exploration to detect injuries of soft tissues as out of 14 injuries only 2 were identified by PMCT.

Conclusions The procedure of whole-body PMCT followed by region-wise CT can be studied for a better PMCT acquisition to detect soft tissue injury findings more precisely. However, the PMCT in this study was able to conclude the cause of death in a more scientific way than the traditional autopsy.

Keywords Virtopsy, Postmortem computed tomography, Forensic autopsy, Trauma, Road traffic accident, Head injury

Background

Forensic radiology is the application of radiological methods to aid in finding the cause of death in the deceased, age estimation in living, and identification of an individual. This includes the usage of X-rays, computed tomography (CT), and magnetic resonance imaging (MRI). Radiology is commonly used for detecting

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fractures of bones, air embolism, foreign body-like bullets, and metallic objects inside the body of the deceased (Thali et al. 2011; Baglivo et al. 2013). Virtopsy is "a virtual alternative to the traditional autopsy, conducted with scanning and imaging technology particularly PMCT (Virtopsy. Wikipedia.org. 2021)." Virtopsy is still in the budding stage in India (Virtual autopsy facility starts at AIIMS Delhi. 2021). Due to emotional and religious reasons, there has always been an aversion towards the traditional autopsy in the relatives of the deceased. Postmortem computed tomography (PMCT) is a noninvasive and preservative procedure as compared to traditional autopsy(TA) (Shen et al. 2014) and could prove an alternative to curtail/minimize internal dissection in certain cases. It not only highlights the exact location, dimensions, and shape of air, fluid, tissues, bones, and even radio-opaque objects like metal inside the body but also provides an assessment of locations that are difficult to reach by conventional autopsy (Thali et al. 2003; Westphal et al. 2014). In road traffic accident cases, the objective of the autopsy surgeon is to certify the cause of death as per the provisions Indian criminal procedure code and also to rule out any foul play. A combination of evaluation of the preliminary inquiry details like witness statements or CCTV footage, the perusal of treatment records, detailed external examination, and internal organ evaluation by PMCT by a forensic medicine expert is sufficient to conclude most of the cases of road accident cases. So, this pilot study was conducted to analyze advantages and limitations of PMCT in comparison with TA in individuals who died due to road traffic accidents. This is a first step towards the goal of developing a protocol for minimal/noninvasive protocol with the use of PMCT which could be implemented especially in cases of non-suspicious road traffic accidental deaths having clear circumstantial evidence.

Methods

The study was conducted in the Department of Forensic Medicine and Toxicology, All India Institute of Medical Sciences (AIIMS), New Delhi. This study is a part of project, Center for Advanced Research and Excellence (CARE) in Virtual Autopsy, a joint venture of two premier institutes of India, the Indian Council of Medical Research (ICMR) Headquarters and AIIMS, New Delhi. The ethical clearance was given by the AIIMS institutional ethics committee vide IEC 577/02.11.2018, RP-29/2018. Consent forms were given and signed by the first-degree relatives (legal heir) of all subjects prior to participation. The study was conducted with the aim of implementing virtual autopsy in India for dignified management of dead. The authors evaluated 10 cases of victims of road traffic accidents (RTA) that were autopsied in the Department of Forensic Medicine and Toxicology in the year 2021. The cases were selected from the second week of two different months to rule out bias in selection of cases.

PMCT examination

In each case, an autopsy was preceded by a PMCT examination using a 16-slice Multi-Slice CT spiral scanner, Toshiba America Medical Systems, Inc. Aquilion Lightning TSX-035A CT. Scanning parameters were 120 kV and 70 mAs. In total, 16×1 mm collimation was used for all the cases for data acquisition. All the raw data was processed into slices of 1 mm thickness. Multiplanar and 3D reconstruction were also done. The PMCT scanning protocol covered the entire body in three series: the first from the top of the head to the shoulders; the second from the neck, above the shoulders to the height of the pubic symphysis; and the third series covered the pelvis and lower limbs. The reconstructions were performed in the soft tissue, bone, and lung window for the thorax (FC18). The results of the study were evaluated with the Vitrea software v.6.9.1. The PMCT findings were analyzed by another forensic medicine specialist in the same department who had acquired training and experience in radiology. The findings were confirmed by a radiology consultant with more than 10 years' experience in radiology.

Traditional autopsy examination

The TA was done by a different forensic specialist in routine courses of their duties, and the findings were interpreted by them respectively. The dissection procedure was usually carried out by a single forensic specialist by Virchow's and Ghon's technique of dissection. A second autopsy surgeon was required in scenarios where a detailed dissection was needed to be carried especially to identify vertebral fractures with underlying contusions and intestines to look for perforations. In such scenarios, the Letulle dissection procedure was carried out. The dissection approach for TA in our department varies from case to case. However, the examination of all the cavities is mandatory for all cases. A special examination was conducted for ensuring concealed bleeding especially in the hidden areas like the areas of scalp between the scalp hair, palpebral conjunctivae, underneath the nasal folds, behind the ear pinna, frenulum of mouth; tongue, nape of the neck, axilla, interdigital spaces of hands and foot, underneath the mammary fold in case of females, intergluteal region, under the scrotum in males and inside the genitals in case of females, and popliteal fossae of the legs. The dissection is initiated by a thorough external examination of the body including the abovementioned areas. The abrasions and contusions are measured with a

measuring tape calibrated in centimeters. If there is any confusion regarding the contusion, an incision is given superficially to confirm the presence of effusion of the blood in the subcutaneous layer.

Examination of fractures

The presence of fractures in the facial region and pelvis region is checked by the palpatory method for the presence of abnormal swelling and crepitus. The long bone fractures are checked for the presence of any discontinuity of the bone. The cranial cavity is opened first followed by the thorax and abdomen. In the cranial cavity, the membrane is stripped away from the skull base to look for skull base fractures. The vertebra fractures are interpreted by the palpatory method and confirmed by careful dissection of soft tissue and looking for the staining of the fracture site. The intercostal muscles are cut along the axis of the ribs so that the ribs are made free from each other and looked for fractures with blood-stained fracture ends.

Examination of hemorrhages

The brain hemorrhages like subdural, subarachnoid, extradural hemorrhages, and intraparenchymal hemorrhages are examined in all the cases by following standard protocols as per literature. The brain parenchymal contusions are confirmed by giving an incision over the suspected places of parenchyma and looking for a shower of petechiae.

Double blinding

The criteria of double binding were strictly maintained during the entire study in order to evaluate the validity of reporting done in PMCT. The assessment was done to study comparison of internal injuries in the area of the head, neck, chest, abdomen, pelvis, and the extremities by both the methods. The evaluation covered analysis of bone structures, soft tissues, the presence of liquids and gases in the body cavities, and pathological spaces. This is a first preliminary observational study in India to highlight the benefits of PMCT in RTA cases to interpret the injuries in a better way, thus maintaining the dignified management of dead.

Results

The youngest victim was 21 years, and the oldest was 67 years. Out of the analyzed cases, 10 were 8 males, and 2 were females. The time between the deceased last seen alive, the discovery of the corpse, and the autopsy was between 1 and 3 days. Hence, forensic investigations were done on fresh cadavers. Overall, there was substantial concordance between the findings of gold standard TA and new test PMCT. A statistical evaluation concluded that the PMCT was able to detect various types of fractures and gas collection inside the body like pneumocephalus, pneumoperitoneum, and pneumothorax accurately all over the body. The sensitivity of the PMCT in detecting the fracture was 100% (confidence interval (CI) = 2.5–100%) except for the vertebra fractures where it is 66.67% (*CI* = 9.43–99.16%). A comparison of the detection rate of fractures in PMCT and TA concluded that fractures were better detected in PMCT. The PMCT was able to detect many fractures which were missed out in the TA. The PMCT detected a total of 27 fractures, while the TA detected a total of 13 fractures from the skull, skull base, vertebra, pelvis, rib, sacroiliac joint, scapula, and humerus in the study population (Table 1, Fig. 1).

In comparison of various types of injuries in the brain, results confirmed that PMCT was able to detect the intraventricular hemorrhages in a better way. The subdural, subarachnoid, and the extradural hemorrhages were equally identified in PMCT and TA. The PMCT had

Table 1 Sensitivity, specificity, and confidence interval (CI) of PMCT in detecting fractures and case-wise comparison of fractures detected in PMCT and TA

Fractures	Sensitivity (CI [in %])	Specificity (CI [in %])	CT detected (%)	TA detected (%)	Both detected	CT Additional
Skull	100 (29.2–100)	63.63 (30.8–89.1)	7 (70%)	3 (30%)	3	4
Skull base	100 (15.8–100)	72.73 (39–94)	5 (50%)	2 (20%)	2	3
Vertebra	66.67 (9.4–99.2)	71.43 (29–96.3)	4 (40%)	3 (30%)	2	2
Pelvis	100 (2.5–100)	77.78 (39.9–97.2)	3 (30%)	1 (10%)	1	2
Rib	100 (29.2–100)	100 (59–100)	3 (30%)	3 (30%)	3	0
Sacroiliac joint disruption	100 (2.5–100)	100 (66.3–100)	1 (10%)	1 (10%)	1	0
Scapula	-	-	3 (30%)	0	0	3
Humerus	-	-	2 (20%)	0	0	2

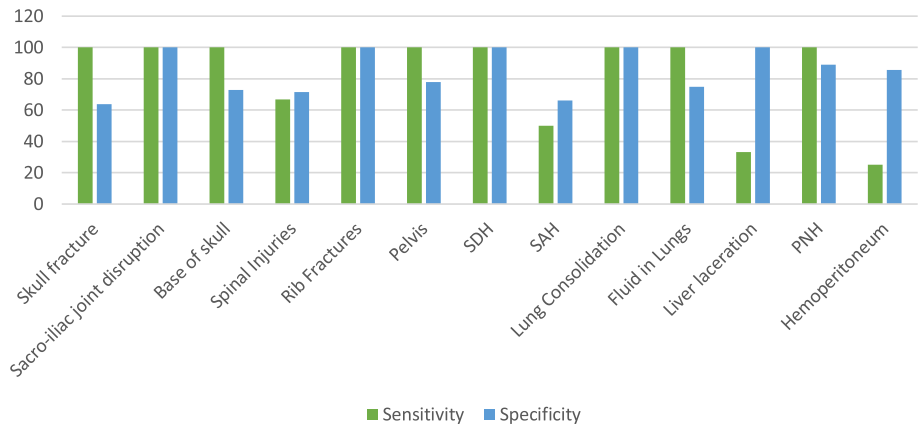

Fig. 1 Sensitivity and specificity of fractures and internal findings detected in PMCT

Table 2 Case-wise comparison of brain findings in PMCT and TA

Areas	CT detected (%)	TA detected (%)	Both detected	CT Additional
Brain parenchyma contusion	0	5 (50%)	-	-
Brain laceration	0	2 (20%)	-	-
Subdural hemorrhage	4	4 (40%)	4	0
Subarachnoid hemorrhage	4	4 (40%)	4	0
Extradural hemorrhage	1	1 (10%)	1	0
Intraventricular hemorrhage	5	2 (20%)	2	3

limitations in interpreting the cerebral contusions and cerebral lacerations (Table 2).

It was also observed that the PMCT was unable to detect contusion of intercostal muscle, lungs, and psoas muscle and lacerations of the spleen and liver. There were no kidney lacerations present in TA in any of the cases. Thus, the results interpretation of kidney lacerations in PMCT could not be evaluated. PMCT detected the air inside the cranium, thorax, and peritoneum which could be a cause of death in multiple cases. Hemosinuses and pneumocranium were noted in majority of cases of the study associated with vault fracture, which was not detected by TA (Table 3).

Table 3 Case-wise comparison of soft tissue injuries and air inside the cavities detected in CT and TA

Areas	CT (%)	TA (%)
Lung contusion	0	3 (30%)
Lung consolidation	2 (20%)	2 (20%)
Intercostal muscle contusion	0	3 (30%)
Psoas muscle contusion	0	2 (20%)
Spleen laceration	0	1 (10%)
Liver laceration	0	3 (30%)
Pneumocranium	5 (50%)	0
Pneumothorax	3 (30%)	0
Pneumoperitoneum	2 (20%)	0
Hemosinus	6 (60%)	0

Discussion

The pilot study analyzed PMCT in contrast to TA in RTA cases. Many authors had previously concluded that PMCT can be an adjunct to TA for postmortem investigation. The authors tried to evaluate the same in their institutional setup. A road traffic incident (RTI) is an accident which is defined "as any injury due to crashes originating from, terminating with or involving a vehicle partially or fully on a public road" (Road traffic accidents 2021). In such a scenario, the incident is generally witnessed by other people. The accident could be captured in the CCTV cameras placed on the road, or there could be a statement of the survivors about the occurrence. Postmortem examination of all the RTA cases is conducted as a part of inquest proceedings under clause 5 of Section 174 of the Code of Criminal Procedure in India (Govenrment of Indian 1973). The law directs the investigating officer to take the body to the designated center for examining the body in all unnatural death cases and in cases without a medically certified

cause of death. In many RTA cases, the deceased undergoes antemortem treatment and later expires during the course of treatment with an undisputed medically certified cause of death. Therefore, because of having an evidence of the incidence, directly or indirectly, it is generally not accepted by relatives to mutilate the body for the sole purpose to determine the cause of death where it is already proven that the person had died due to the injuries sustained in RTA. This adds to their emotional trauma and grief. This led the authors to undertake this study to compare the findings of PMCT and TA in order to replace the internal dissection of the body in the near future.

The PMCT has its own advantages based on the authors observation while conducting this pilot study as listed below:

- The time taken to complete the procedure is less than 15 min which includes taking the body out from cold chamber, identification procedures by the relatives, shifting the body to take to scan area, and complete PMCT scanning.
- PMCT is non-invasive and hence provides dignified management of the body which is welcomed by relatives belonging to all the religions in India as TA is still considered against religious beliefs in all religions.
- PMCT is a non-mutilating procedure and preserves the findings present in the body. This also assists in the better scientific interpretation of the findings as no iatrogenic artifacts are introduced, thereby helping autopsy surgeons to conclude the cause of death in RTA cases.
- The whole body is being scanned within minutes and converted into images to be stored for future evaluation. This data prevents and reduces the need to exhumation or second autopsy in cases where the suspicion arises in the future.
- This can also be a piece of evidence in the court, as the findings can be easily shown and explained to the judiciary officials.

The results of the present study proved that PMCT was able to find most of the relevant internal injuries in RTA cases inspite of few limitations, and cause of death can be given based on PMCT examination (Tables 4, 5, and 6). Few authors have studied whole-body CT in trauma cases similar to our study (Worasuwannarak et al. 2020; Scholing et al. 2009), while few other studies concentrated on region-wise study like head (Legrand et al. 2019; Jacobsen et al. 2009) and cervical region (Makino et al. 2017; Uhrenholt and Boel 2010). The abovementioned studies showed mixed results similar to our study. They had concluded that the PMCT was better in interpreting pneumocephalus, pneumothorax, pneumoperitoneum, and ventricular hemorrhages of brain and facial bone fractures. Based on the observations in this study, the authors conclude that interpretation of the ventricular hemorrhages of the brain is much better in PMCT. The integrity of the brain was maintained while scanning; hence, minimal ventricular hemorrhages are better viewed in PMCT. In TA, while removing and dissecting the brain, they could be missed due to washing, etc. Even though minimal ventricular hemorrhages are less significant medically, medicolegally, it is an important finding. Our study in addition to the abovementioned findings was able to detect precisely the hemosinuses, scapula fractures, vertebral fracture, pelvis fractures, and hairline fractures of long bones which can be easily missed in TA in scenarios where the individual is hefty and the presence of rigor mortis of the muscles surrounding the fracture makes the region rigid and difficult to look for the crepitus as observed in the present study (Fig. 2). Wijetunga, O'Donnell, Varma, Cameron, Burke, and Smith reported a scenario similar to the present study where the traditional autopsy reported only a knee joint dislocation; however, PMCT confirmed the presence of an intact knee joint with a fracture in fibula bone (Wijetunga et al. 2019). Moskata, Wozniak, and Kluza reported "a statistically significant difference in favor of the use of combined techniques for the fractures of bones of the skull, spine, clavicle, scapula, lower legs bones and the presence of pneumothorax" (Moskata et al. 2016). In the present study, the PMCT was able to find the findings mentioned by Moskata, Wozniak, and Kluza; however, statistical test could not be applied due to less sample size. The results of our study are in concordance with Jalalzadeh, Giannakopoulos, and Berger who in their systematic review suggested that PMCT is an adequate alternative that detects most injuries (Jalalzadeh et al. 2015). A comparison of an autoptic and scan image is shown in Fig. 3.

In many studies, the PMCT was conducted to supplement the TA, and PMCT analysis was conducted prior to TA (Urbanik et al. 2009; Kawasumi et al. 2012; Thomsen et al. 2009; Ross et al. 2012; Cittadini et al. 2010; Aghayev et al. 2008). This led to increased detection of injuries at TA. The highlight of this study was the strict adherence to the double blinding so that there is an independent conduction of the examination and assessment both in PMCT and TA. This procedure helped to analyze the benefits and shortcomings of the PMCT over TA. The possible reasons based on the authors observation regarding the findings being interpreted by PMCT but missed out in TA are listed in Table 7.

Daly, Abboud, Ali, Sliker, and Fowler stated that the common findings missed at PMCT were superficial

Table 4 Case-wise comparative summary of findings observed by PMCT and TA

Case no	1		2		3		4		5		6		7		8		9		10	
	CT	TA	CT	TA	CT	TA	CT	TA	CT	TA	CT	TA	CT	TA	CT	TA	CT	TA	CT	TA
Vault fracture	X	X	✓	X	X	X	✓	✓	✓	X	X	X	✓	X	✓	✓	✓	X	✓	✓
Skull base fracture	X	X	X	X	X	X	✓	X	✓	X	✓	X	✓	X	✓	✓	X	X	X	✓
Subdural hemorrhage	X	X	X	X	X	X	X	X	X	X	✓	✓	✓	✓	✓	✓	X	X	✓	✓
Subarachnoid hemorrhage	✓	✓	X	X	X	X	X	X	X	X	X	X	✓	✓	✓	✓	X	X	✓	✓
Extradural hemorrhage	X	X	✓	✓	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Intraventricular hemorrhage	✓	X	X	X	X	X	✓	✓	✓	✓	X	X	✓	X	✓	X	X	X	X	X
Brain contusion	X	X	X	X	X	X	X	✓	X	X	X	✓	X	✓	X	✓	X	X	X	✓
Pneumocephalus	X	X	✓	X	X	X	✓	X	✓	X	X	X	✓	X	✓	X	X	X	X	X
Hemosinus	X	X	X	X	X	X	✓	X	✓	X	✓	X	✓	X	✓	X	✓	X	X	X
Facial bone fracture	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	✓	X	X	X
Clavicle fracture	X	X	X	X	X	X	✓	X	X	X	X	X	X	X	X	X	X	X	X	X
Rib fracture	✓	✓	X	X	✓	✓	X	X	X	✓	✓	X	X	X	X	X	X	X	X	X
Lung contusion	X	✓	X	X	X	✓	X	X	X	✓	X	X	X	X	X	X	X	X	X	X
Pneumothorax	✓	X	X	X	✓	X	X	X	X	X	✓	X	X	X	X	X	X	X	X	X
Lung consolidation	X	X	X	X	✓	✓	X	X	X	X	X	X	X	X	X	X	✓	✓	X	X
Spleen laceration	X	X	X	✓	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Liver laceration	X	X	X	✓	X	✓	X	X	X	✓	X	X	X	X	X	X	X	X	X	X
Hemoperitoneum	X	X	X	✓	X	✓	X	X	X	✓	X	✓	X	X	X	X	X	X	✓	X
Pneumoperitoneum	X	X	✓	X	✓	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Humerus fracture	✓	X	X	X	X	X	X	X	X	X	✓	X	X	X	X	X	X	X	X	X
Scapula fracture	X	X	X	X	✓	X	✓	X	✓	X	X	X	X	X	X	X	X	X	X	X
Ulna fracture	X	X	X	X	✓	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Vertebra fracture	✓	✓	✓	X	✓	X	X	X	✓	✓	X	✓	X	X	X	X	X	X	X	X
Pelvis fracture	X	X	X	X	✓	X	X	X	✓	✓	✓	X	X	X	X	X	X	X	X	X
Femur fracture	X	X	X	X	✓	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tibia fracture	X	X	X	X	X	X	X	X	X	X	✓	X	X	X	X	X	X	X	X	X
Fibula fracture	X	X	X	X	X	X	X	X	X	X	✓	X	X	X	X	X	X	X	X	X
Sacroiliac joint disruption	X	X	X	X	X	X	X	X	✓	✓	X	X	X	X	X	X	X	X	X	X

Table 5 Summary of PMCT findings relative to TA in 10 cases

PMCT findings relative to TA findings	Case number
Ability to show gas-related injuries not detected at autopsy	1, 2, 3, 5, 6, 7, 8
Ability to show scapula fractures not detected at autopsy	3, 4, 5
Ability to show vertebra fractures	2, 3
Ability to show skull fractures	2, 5, 7, 9
Ability to show intraventricular bleed in the brain	1, 7, 8
Inability to show liver laceration	2, 3, 5
Inability to show spleen laceration	2
Inability to show brain contusion	4, 6, 7, 8, 10
Inability to show lung contusion	1, 3, 5

liver laceration reported by various authors (Daly et al. 2013). Christe et al. concluded that the life-threatening liver and spleen lacerations can be interpreted at PMCT (Christe et al. 2009). The authors in contrast observed that brain contusions, lung contusions, intercostal muscle contusion, liver laceration, and spleen laceration are difficult to be interpreted. This can be due to effect of the postmortem change like hypostasis in the organs, decomposition changes, and the freezing effect due to preservation. The freezing effect of the organs is visualized in PMCT as a hypodensity in comparison to a nonfrozen tissue (Sugimoto et al. 2016). The abovementioned factors might have made interpreting the soft tissue injuries a bit difficult. The authors are hopeful that with increased experience in PMCT evaluations, such difficulties can be overcome in due course of time. The soft tissue findings related to aortic dissection, heart rupture, lung laceration, cardiac tamponade, kidney laceration, perinephric hematoma, retroperitoneal hemorrhage, urinary bladder contusion, and rupture need further exploration as these were not present in the studied 10 cases which could be a limitation of the study.

Table 6 Comparison of cause of death by PMCT and TA

Case	Cause of death from PMCT findings	Cause of death from TA findings
1	Complications of multiple injuries sustained to the brain, chest, and vertebra	Shock consequent upon surface impact or blunt force trauma to the head and chest
2	Complications of multiple injuries sustained to the brain, abdomen, and vertebra	Shock consequent upon sepsis and blunt trauma to abdomen
3	Multiple bone, chest, and abdomen injuries sustained and its complications	Hemorrhagic shock due to polytrauma
4	Craniocerebral injuries and its complications	Head injury consequent upon surface impact or blunt force trauma to head
5	Complication of injuries sustained to craniocerebrum chest and pelvis	Septicemia due to polytrauma
6	Injuries sustained to craniocerebrum and pelvis	Polytrauma due to blunt force/surface impact
7	Complications of injuries sustained to craniocerebrum chest, pelvis, and lower limb	Head injury and its complications due to blunt force/surface impact
8	Craniocerebral injuries and its complications	Craniocerebral injuries and its complications
9	Head injury and its complications	Sepsis arising as a complication of trauma to chest
10	Complication of craniocerebrum and abdomen injuries	Craniocerebral injuries and its complications

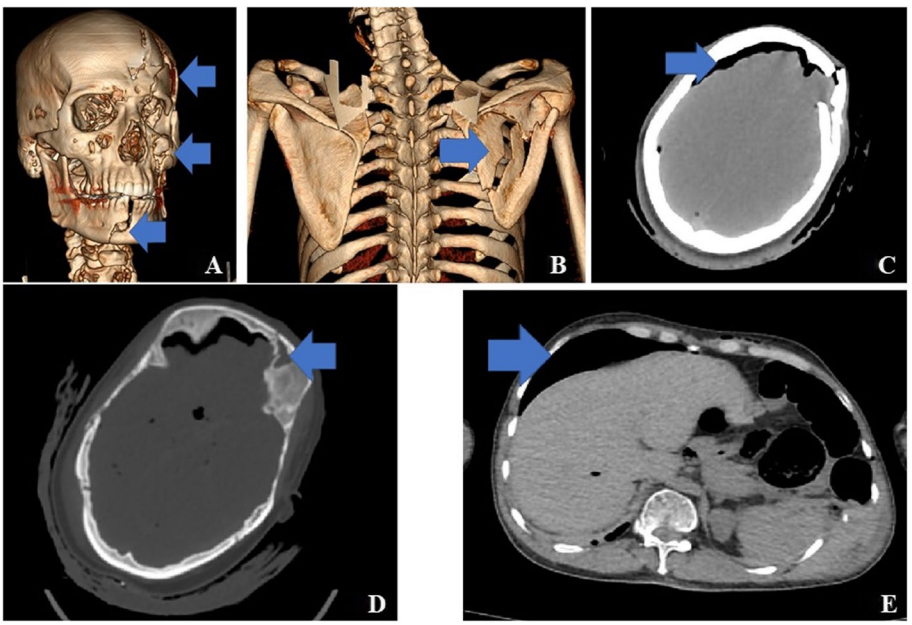

Fig. 2 PMCT findings of fracture and air inside the cranial cavity and peritoneum. **A** Left sided — frontal bone fracture, facial fracture, and mandible fracture. **B** Right scapula communited fracture. **C** Pneumocephalus underlying left frontal vault fracture. **D** Left frontal hemosinus underlying left frontal bone fracture. **E** Right pneumoperitoneum — air under the diaphragm

Conclusions

Cafarelli, Grilli, Zizzo, Giuseppe, Giuliani, Mahakkanukrauh, Pinto, and Guglielmi suggested the implications of imaging modalities in forensic medicine and focused on the combined workup of radiologists and forensic pathologists across the world (Cafarelli et al. 2019). This pilot study is also directed towards replacing/augmenting the TA with PMCT in the near future in RTA cases in India. The overall results showed that the PMCT is best to detect the fractures of the skull and facial bones, fractures of the clavicle, scapula, and vertebra more precisely than TA. PMCT should be the investigation of choice for air inside the cavities of the body and hemosiuns, while it needs further exploration to detect injuries of soft tissues. An extended analysis with increased sample size is required for the sensitivity to detect the findings in soft tissue injuries. The procedure of whole-body PMCT followed by region-wise PMCT can be tried for better visualization of the findings. Based on the results of this study, the authors

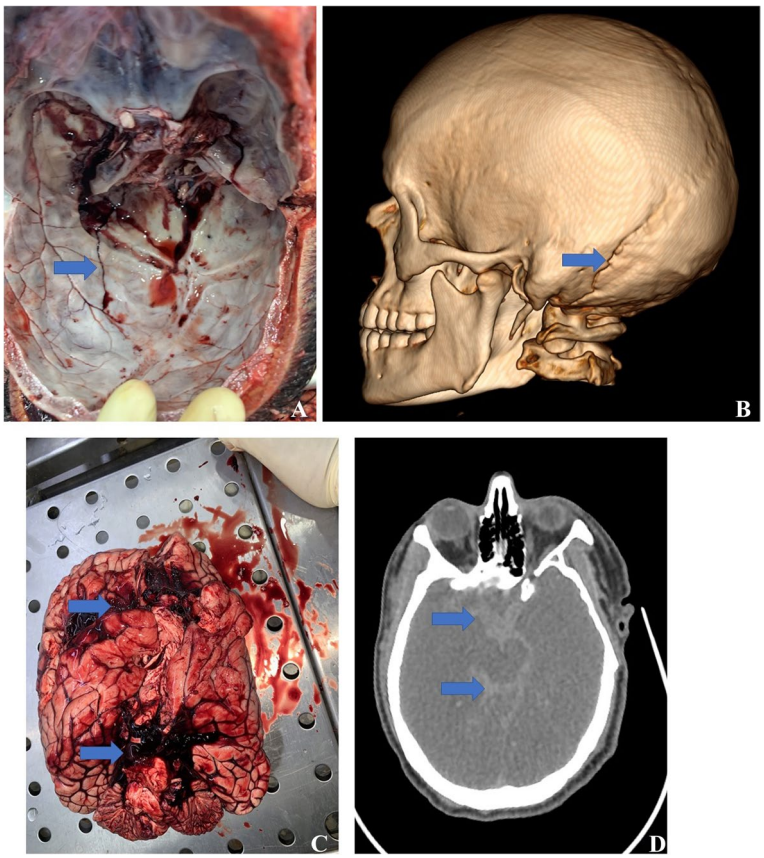

Fig. 3 **A** Fissure fracture left occipital bone in TA. **B** Fissure fracture left occipital bone in PMCT. **C** Thick subdural hemorrhage over the base of the brain in TA. **D** Thick subdural hemorrhage over the base of brain in PMCT

Table 7 Reasons for nondetection of internal findings at TA

Findings	Reasons
Hemosinus	Difficult to access without mutilating the soft tissues and bones of the face
Facial fracture	Time-consuming techniques like superficial subcutaneous dissection on the face are required to interpret the exact fractures of the bones which at times may disfigure the face if not dissected patiently. Chances of overreporting the fractures on the account of palpation technique alone
Clavicle fracture	The soft tissues need to be cleared to locate the fracture unless there is gross dislocation
Scapula fracture	Difficult to find even by palpation due to thick muscles of the back covering the bone
Pelvis fracture	The genitals and the soft tissues over the groin need to be cleared to locate the fracture which fails to ensure the dignified management of dead, unless there is gross dislocation
Hairline fractures of long bones	To locate the hairline fractures at TA, the exact site of the fracture on the bone needs to be known to explore the site. PMCT does a better job to document the same
Air inside the body cavity (head, chest, abdomen)	Due to the mutilating procedure for examination in TA, the air collected inside the cavity is escaped, and hence, the findings are destroyed

are keen to explore the use of angiography techniques in the RTA cases considering the conclusions reported by Marco D. E. et al. and Russa R. L. et al. (Russa et al. 2019; Marco et al. 2018). The PMCT angiography (PMCTA) together with PMCT-guided biopsy helps in the retrieval of the sample from the suspected lesion. The histopathological examination of the same will solve the issues related to the vitality of the injury. Hence, the authors would propose and like to perform a holistic methodology of conducting PMCT examination along with ancillary investigations like PMCTA, PMCT-guided biopsy, and histopathological examination (if needed) in the upcoming study of RTA cases with increased sample size.

Abbreviations

PMCT	Postmortem computed tomography
CT	Computed tomography
MRI	Magnetic resonance imaging
TA	Traditional autopsy
RTA	Road traffic accidents
CI	Confidence interval
PMCTA	Postmortem computed tomography angiography

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Authors' contributions
Dr. KVRK contributed to the design of the study, performed the experiments, analyzed and interpreted the data, and wrote the paper. Dr. AK performed the experiments and wrote the paper. Dr. AY was responsible for designing the study, performing the experiments, and contributing the reagents, materials, analysis tools, or data. Dr. MJ contributed reagents, materials, analysis tools, or data. Dr. SKG designed the study, performed the experiments, and contributed reagents, materials, analysis tools, or data. Dr. VC assisted in performing the experiments and writing the paper. Dr. BD contributed reagents, materials, analysis tools, or data and revised and edited the final draft, Dr. AES contributed reagents and materials, and Dr. APSC contributed reagents and materials. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets supporting the conclusion of this study are included in the manuscript.

Declarations

Ethics approval and consent to participate
The ethical clearance was given by the AIIMS institutional ethics committee vide IEC 577/02.11.2018, RP-29/2018. Consent forms were given and signed by the first-degree relatives (legal heir) of all subjects prior to participation.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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References

Aghayev E, Christe A, Sonnenschein M, Yen K, Jackowski C, Thali MJ et al (2008) Postmortem imaging of blunt chest trauma using CT and MRI: comparison with autopsy. J Thorac Imaging 23(1):20–27

Baglivo M, Winklhofer S, Hatch GM, Ampanozi G, Thali MJ, Ruder TD (2013) The rise of forensic and post-mortem radiology-analysis of the literature between theyear 2000 and 2011. J Forensic Radiol Imaging 1:3–9. https://doi.org/10.1016/j.jofri.2012.10.003

Cafarelli FP, Grilli G, Zizzo G, Giuseppe B, Giuliani N, Mahakkanukrauh P, Pinto A, Guglielmi G (2019) Post-mortem imaging: an update. Semin Ultrasound CT MRI 40(1):86–93. https://doi.org/10.1053/j.sult.2018.10.012

Christe A, Ross S, Oesterhelweg L, Spendlove D, Bolliger S, Vock P et al (2009) Abdominal trauma-sensitivity and specificity of postmortem non-contrast imaging findings compared with autopsy findings. J Trauma 66(5):1302–1307

Cittadini F, Polacco M, D'Alessio P, Tartaglione T, De Giorgio F, Oliva A et al (2010) Virtual autopsy with multidetector computed tomography of three cases of charred bodies. Med Sci Law 50(4):211–216

Code of Criminal Procedure, 1973. Govenrment of Indian. 2021. [Cited 11.12.2021]. Available at. https://indiankanoon.org/doc/411677/..

Daly B, Abboud S, Ali Z, Sliker C, Fowler D (2013) 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 225(1):20–26

Jacobsen C, Bech BH, Lynnerup N (2009) A comparative study of cranial, blunt trauma fractures as seen at medicolegal autopsy and by computed tomography. BMC Med Imaging 16:9–18

Jalalzadeh H, Giannakopoulos GF, Berger F et al (2015) Post-mortem imaging compared with autopsy in trauma victims – a systematic review. Forensic Sci Int 257:29–48

Kawasumi Y, Hosokai Y, Usui A, Saito H, Ishibashi T, Funayama M (2012) Post-mortem computed tomography images of a broken piece of a weapon in the skull. J Radiol 30(2):167–170

La Russa R, Catalano C, Di Sanzo M, Scopetti M, Gatto V, Santurro A et al (2019) Postmortem computed tomography angiography (PMCTA) and traditional autopsy in cases of sudden cardiac death due to coronary artery disease: a systematic review and meta-analysis. Radiol Med 124:109–117. https://doi.org/10.1007/s11547-018-0943-y

Legrand L, Delabarde T, Scemama RS et al (2019) Comparison between postmortem computed tomography and autopsy in the detection of traumatic head injuries. J Neuroradiol 47(1):5–12. https://doi.org/10.1016/j.neurad.2019.03.008

Makino Y, Yokota H, Nakatani E et al (2017) Differences between postmortem CT and autopsy in death investigation of cervical spine injuries. Forensic Sci Int 281:44–51. https://doi.org/10.1016/j.forsciint.2017.10.029

Marco DE, Vacchiano G, Frati P, Russa RL, Santurro A, Scopetti M et al (2018) Evolution of post-mortem coronary imaging: from selective coronary arteriography to post-mortem CT-angiography and beyond. Radiol Med 123(5):351–358. https://doi.org/10.1007/s11547-018-0855-x

Moskata A, Wozniak K, Kluza P et al (2016) The importance of post-mortem computed tomography (PMCT) in confrontation with conventional forensic autopsy of victims of motorcycle accidents. Leg Med 18:25–30

Road traffic accidents. National Health Portal.org. 2021[updated 2015 Sep28;cited 2021 Dec 11]. Availabelfrom:https://www.nhp.gov.in/road-traffic-accidents_pg.

Ross S, Ebner L, Flach P, Brodhage R, Bolliger SA, Christe A et al (2012) Post-mortem whole-body MRI in traumatic causes of death. AmJ Roentgenol 199(6):1186–1192

Scholing M, Saltzherr TP, Fung Kon Jin PH, Ponsen KJ, Reitsma JB, Lameris JS et al (2009) The value of postmortem computed tomography as an alternative for autopsy in trauma victims: a systematic review. Eur Radiol. 19(10):2333–2341

Shen CY, Chen ZL, Chen XS (2014) Revolution of forensic medicine: research status and prospect of virtual autopsy. Med Jurisprud 6:82–89

Sugimoto M, Hyodoh H, Rokukawa M, Kanazawa A, Murakami R, Shimizu J et al (2016) Freezing effect on brain density in postmortem CT. Leg Med 18:62–65

Thali MJ, Yen K, Vock P, Ozdoba C, Kneubuehl BP, Sonnenschein M, Dirnhofer R (2003) Image-guided virtual autopsy findings of gunshot victims performed with multi-slice computed tomography (MSCT) and magnetic resonance imaging (MRI) and subsequent correlation between radiology and autopsy findings. Forensic SciInt 138:8–16. https://doi.org/10.1016/S0379-0738(03)00225-1

Thali MJ, Viner MD, Brogdon BG (2011) Definitions in forensics and radiology. In: Brogdon BG (ed) Brogdon's Forensic Radiology, 2nd edn. CRC Press, United States of America, pp p1-7

Thomsen AH, Jurik AG, Uhrenholt L, Vesterby A (2009) An alternative approach to computerized tomography (CT) in forensic pathology. Forensic Sci Int 183(1):87–90

Uhrenholt L, Boel LW (2010) Contributions from forensic imaging to the investigation of upper cervical fractures. J Forensic Sci 55(6):1598–1602

Urbanik A, Chrzan R, Woz´ niak K, Moskała A (2009) Post-mortem CT examination- own experiences. Pol. J. Radiol. 74(4):55–63

Virtopsy. Wikipedia.org. 2021[updated 2021 Nov 26; cited 2021 Dec 11]. Availabelfrom:https://en.wikipedia.org/wiki/Virtopsy.

Virtual autopsy facility starts at AIIMS Delhi. Here's how it works. NDTV.org. 2021[updated 2021 Mar 21; cited 2021 Dec 11]. Availabelfrom:.https://www.ndtv.com/delhi-news/virtual-autopsy-facility-starts-at-aiims-delhi-heres-how-it-works-2395180.

Westphal SE, Apitzsch JC, Penzkofer T, Kuhl CK, Mahnken AH, Knüchel R (2014) Contrast-enhanced postmortem computed tomography in clinical pathology: enhanced value of 20 clinical autopsies. HumPathol 45:1813–1823. https://doi.org/10.1016/j.humpath.2014.05.007

Wijetunga C, O'Donnell C, Varma D, Cameron P, Burke M, Smith K et al (2019) Injury detection in traumatic death: PMCT vs. open autopsy. J Forensic Radiol Imag. 20:100349. https://doi.org/10.1016/j.jofri.2019.100349

Worasuwannarak W, Peonim V, Srisont S, Udnoon J, Chudoung U, Kaewlai R (2020) Comparison of postmortem CT and conventional autopsy in five trauma fatalities. Forensic Imaging 22:200–209

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