



Post-mortem computed tomography improves completeness of the trauma registry: a single institution experience

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Abstract

Purpose To describe our institutional experience with post-mortem computed tomography (PMCT) and its impact on decedent injury severity score (ISS) and to assess the adequacy of emergently placed support medical devices.

Methods Over a 5-year period, patients who died at or soon after arrival and have physical exam findings inconsistent with death were candidates for inclusion. Whole body CT was performed without contrast with support medical devices left in place. ISS was calculated with and without the PMCT findings. PMCT results were compared to autopsy findings, if performed. The location of support medical devices was documented.

Results A total of 38 decedents underwent PMCT, including 53.1% males and a mean age of 42.0 years. Pre-PMCT ISS based on physical exam findings alone was 5.2 (range 0–25), including 16 with ISS = 0. Post-PMCT ISS using the additional imaging data was 50.3 (range 21–75), including 15 with ISS = 50 or greater. Nearly half (47.4%) had at least one support medical device that was either malpositioned or suboptimally positioned, including 26.3% with malpositioned airway devices, 10.3% with malpositioned intra-osseous catheters, and 100% with malpositioned decompressive needle thoracotomies.

Conclusions PMCT adds value in identifying injuries that otherwise may have gone undetected in lieu of a formal autopsy, thus creating a more complete trauma registry. The identification of malpositioned support lines and tubes allows for educational feedback to the first responders and trainees. Institutions with a low formal autopsy rate for trauma victims may benefit from developing a PMCT program.

Keywords Trauma · Mortality · Post-mortem CT

Introduction

Trauma results in the largest impact on life year lost, more than that of cancer, heart disease, and HIV combined [1].

The current literature suggests that mortality is seen in ~6–7% of trauma patients, with ~0.8% trauma deaths occurring at or immediately after arrival in the emergency department/trauma center [1], often prior to the acquisition of medical imaging.

Injury severity score (ISS) is a means to objectively quantify trauma severity, based on the injuries acquired by any investigative method (such as physical exam, medical record review, laboratory tests, imaging tests, and autopsy). ISS is an anatomically based metric calculated by assessing injury severity for six body regions. The ISS range is from 0 (no injuries) to a maximum of 75 (fatal injuries), with an ISS > 15 considered to indicate the presence of severe trauma [2, 3]. A 50% mortality is seen in the ISS 40–50 range for patients age < 50 years and in the 25–35 range for patients age > 50 years [3].

A review of our institution's Trauma Registry found a number of trauma mortalities with low ISS who otherwise would have been expected to survive. However, a low historical autopsy rate of 12% for the trauma mortalities from our

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institution prohibited full injury identification, as an “external examination” only was often chosen over formal autopsy by the forensic pathologist. Therefore, without immediate post-mortem imaging, complete documentation of injuries may never be determined for a significant percentage of our institutions’ trauma mortalities.

Given this context, the Trauma/Critical Care and Radiology services at our institution developed a post-mortem computed tomography (PMCT) program where trauma patients who arrive dead on arrival or who died soon after presentation to the trauma center are candidates for whole body PMCT to identify clinically occult internal injuries. This additional information was then be used to determine ISS and creates a more complete institutional trauma registry.

The purpose of this study was to document our institutional experience with PMCT in the setting of accidental traumatic death, the impact of PMCT on ISS, and assess the location of emergently placed support medical devices for provider educational purposes.

Materials and methods

A PMCT program was developed at our institution’s primary level 1 trauma center for the purposes of: (1) identifying clinically occult injuries that had the potential to be lost in lieu of a formal autopsy, (2) creating a more complete trauma registry, and (3) assessing support medical device positioning. Internal funding for the acquisition and interpretation of these exams was obtained; neither the decedent’s insurance nor the decedent’s family was charged for this elective post-mortem test.

This was a 5-year review with inclusive dates from January 1, 2013, through December 31, 2017. Decedents who met the following criteria were eligible for PMCT: have blunt trauma mechanism of injury, decedents who died at or soon after (within 60 min) arrival in the trauma bay, have not undergone CT imaging and/or surgical exploration in the operating room prior to death, *and* have physical exam findings inconsistent with deceased state, as determined by the trauma surgery attending. Lifesaving surgical interventions performed in the trauma bay, such as thoracotomy and internal cardiac massage, did not disqualify the decedent from inclusion. Decedents who had the following criteria were excluded: admission to an inpatient setting prior to death, or prior CT imaging (including from outside institutions), surgery prior to CT imaging, or suspected non-accidental death (such as gunshot or stab wound in the setting of interpersonal violence).

Imaging protocol

The ordering provider, typically a trauma surgeon, obtained verbal and/or written consent from the decedent’s family. All scans were performed within 2 h of time of death. The CT

scanners utilized were located adjacent to the emergency department and trauma center, and were available 24 h a day for clinical use, which aided in the speed of scan acquisition.

CT scans were performed without contrast from the top of the head to the toes on either a 64 or 128 multi-detector CT scanner (Philips Healthcare, Best, The Netherlands) using a reference of 240 mAs and 120 kVp. All lines, tubes, and other support medical devices, if present, were intentionally left in place but disconnected from their respective devices (such as intravenous pumps, ventilators, etc). CT images of the head, face, and cervical spine were reconstructed at 2-mm slice thickness in the axial, sagittal, and coronal planes. CT images of the chest, abdomen, pelvis, and lower extremities were reconstructed at 4-mm slice thickness in the axial, sagittal, and coronal planes. Images were sent to a sequestered worklist on a clinical production PACS system (Fuji Synapse, Stamford, CT) and archived in perpetuity.

Reporting and data analysis

All studies were interpreted by one of two board certified radiologists with 9 and 11 years of experience with trauma and emergency radiology. The PMCT scans were interpreted prior to the generation of a formal autopsy report, if performed. The finalized radiology report was then included in the decedent’s permanent medical record. Trained trauma registrars, using injury information from clinical exam and PMCT scan information, conducted analysis of each patient’s ISS, with “pre-PMCT” ISS calculated using only clinically obtained information, and “post-PMCT” ISS calculated using a combination of both clinical information and the results of PMCT. Pre- and post-PMCT ISS were compared. The injuries seen on PMCT were compared to those identified on full formal autopsy, if performed. Concordance between PMCT and autopsy was calculated. When possible, each injury counted as 1 for the purposes of the concordance analysis (ex., 1 rib fracture = 1 injury). However, for simplification and the purposes of this manuscript, complex injuries were grouped into a single injury and counted as 1 injury (ex. naso-orbito-ethmoid complex fractures = 1 injury). An injury to a single organ was counted as 1 injury if the exact extent of the injury from the autopsy report was unclear (ex., “Multiple liver lacerations” = 1 injury). Anatomically overlapping injuries identified at both autopsy and PMCT were labeled as concordant.

Results

A total of 38 decedents met the inclusion criteria and underwent PMCT during the study period, including 23 males (60.5%). For two patients, the age was unknown. For the

remaining 36 individuals, the average age was 42.0 years (range 15–87 years). All patients initially arrived with mechanical airway devices in place and had a Glasgow Coma Scale (GCS) of 3.

The mean ISS for the cohort based on physical exam findings alone was 5.2 (range 0–25), including 31 patients with ISS < 15, and 16 patients with ISS 0. The mean ISS using the information obtained from PMCT was 50.3 (range 21–75), with 15 patients with an ISS equal to or greater than 50.

A total of 14 patients (36.8%) were referred to the local county coroner’s office, resulting in four full formal autopsies, for an autopsy rate of 10.5%. Ten underwent an “external examination only” assessment (26.3%). The ISS calculated based on autopsy findings for the 4 patients ranged from 50 to 75 (1 with ISS 50 and 3 with ISS 75). Three of the decedents with autopsy were given ISS of 75 following autopsy, consistent with the PMCT ISS. One decedent was assigned an ISS of 29 based on PMCT findings. However, PMCT failed to recognize the liver injuries, mesenteric injury, and pancreatic head injury and was assigned an ISS of 50 following autopsy.

Each of the four formal autopsies revealed injuries not prospectively identified on PMCT; and conversely, there were injuries seen on PMCT that were not identified at autopsy (Table 1). Overall, more injuries were found on PMCT than at autopsy. The PMCT scans for these 4 individuals were reassessed by the two radiologists, with special attention given to the autopsy findings not seen on PMCT prospectively

(Table 1). Patient 1 was noted to have left laryngeal hemorrhage at autopsy that was not visible on PMCT, even in retrospect. Patient 1 was also noted to have two right hepatic lobe lacerations, which in retrospect, were likely present on the PMCT but were partially obscured by beam hardening artifact from the decedents adjacent arms (Fig. 1, Table 1). Patient 2 was noted to have “multiple liver lacerations, predominantly in the right lobe”, massive mesenteric hemorrhage, and a pancreatic body hemorrhage (Table 1). Upon retrospective review of the PMCT, none of these three injuries were visible. Patient 3 was noted to have right periadrenal hemorrhage, right ascending colon hemorrhage, contused adjacent colonic mesentery, and a right lateral seventh rib fracture (Table 1). In retrospect, neither the periadrenal hemorrhage, ascending colon hemorrhage, nor the colonic mesenteric contusion was visible on PMCT. However, upon reassessment of the PMCT images, the right lateral ribs, 7–9 were noted to be fractured (not shown). Patient 4 was noted to have right basal ganglia and midbrain hemorrhage at autopsy (Table 1). In retrospect, the midbrain hemorrhage is visible on PMCT, but the right basal ganglia hemorrhage is not confidently seen (not shown). It is possible that the extensive hemorrhage resulted in distorted anatomy, making precise localization difficult. Mean concordance between PMCT and autopsy was 70.0% (range 58.8–86.7%).

Support medical devices and tubes were left in place for all PMCT scans (Fig. 2). All 38 individuals were intubated with either an endotracheal tube (ETT) or other mechanical airway

Table 1 Autopsy versus post-mortem CT findings

Autopsy versus Post-Mortem CT Findings			
Patient 1			
PMCT Injuries	Autopsy Injuries	Number of PMCT Injuries	Number of Autopsy Injuries
HEAD AND FACE	HEAD AND FACE		
Bilateral nasal bone fractures		2	N/D
Hard palate fracture		1	N/D
Right mandibular condyle fracture		1	N/D
		1	N/D
Right condylar neck fracture		1	N/D
Right TMJ dislocation		1	N/D
Submental soft tissue laceration		1	1
NECK	NECK		
Malpositioned airway device	Hemorrhage left larynx	N/D	1
CHEST	CHEST		
Right 1-8 rib fractures	Right 1-12 rib fractures	8	12
Right 7-8 costal cartilage fractures		2	N/D
Left 1-8 rib fractures	Left ribs 5-6 fractures	8	2
Mediastinal hemorrhage	Mediastinal hemorrhage	1	1
Large left hemopneumothorax	Large left hemopneumothorax	1	1
Small right pneumothorax		1	N/D
Bilateral lung contusions	Bilateral lung contusions	2	2
Sternum fx	Sternum fx	1	1
ABDOMEN/PELVIS	ABDOMEN/PELVIS		
Left hip dislocation		1	N/D
Left acetabular fx	Liver lacerations x 2	N/D	2
EXTREMITIES	EXTREMITIES		
Left calcaneus fx		1	N/D
Left tibia fx		1	N/D
TOTAL		35	23
Concordance = 23/35 = 66.7%			

Patient 2			
PMCT Injuries	Autopsy Injuries	Number of PMCT Injuries	Number of Autopsy Injuries
HEAD AND FACE	HEAD AND FACE		
Left nasal bone fracture		1	N/D
Subgaleal hematoma	Subgaleal hematoma	1	1
NECK	NECK		
N/D	N/D	N/D	N/D
CHEST	CHEST		
Small right pneumothorax	Right pneumothorax	1	1
Moderate left hemopneumothorax	Left hemopneumothorax	1	1
Mediastinal hemorrhage	Mediastinal hemorrhage	1	1
Suspected aortic injury	Aortic intimal injuries	1	1
Bilateral multifocal lung contusions	Right lung injury	2	1
Right 6th rib fx		1	N/D
Right retroperitoneal contusion	Bilateral adrenal hemorrhage	1	2
	Multiple liver lacerations	N/D	1
Right retroperitoneal contusion	Massive mesenteric hemorrhage	N/D	1
	Pancreatic body hemorrhage	N/D	1
ABDOMEN/PELVIS	ABDOMEN/PELVIS		
Left acetabulum fx	Left ilium fracture	1	1
Prepubic and left inguinal subcutaneous contusions	Periosteal and left testicle hemorrhage	1	1
Left 3-5 transverse process fractures		3	N/D
EXTREMITIES	EXTREMITIES		
N/D	N/D	N/D	N/D
TOTAL		15	13
Concordance 13/15 = 86.7%			

Patient 3			
PMCT Injuries	Autopsy Injuries	Number of PMCT Injuries	Number of Autopsy Injuries
HEAD AND FACE	HEAD AND FACE		
Skull base fracture	Posterior cranial fossa fracture	1	1
	Subdural hematoma	N/D	1
	Subarachnoid hemorrhage	N/D	1
NECK	NECK		
N/D	N/D	N/D	N/D
CHEST	CHEST		
Bilateral pulmonary contusions	Bilateral lung hilum contusions	2	2
Moderate left pneumothorax	Left pneumothorax	1	1
Right 7-9 rib fractures	Right 7th rib fracture	3	1
Sternal fracture		1	N/D
ABDOMEN/PELVIS	ABDOMEN/PELVIS		
	Right adrenal hemorrhage	N/D	1
	Right ascending colon hemorrhage	N/D	1
	Right ascending colon mesenteric contusion	N/D	2
Bilateral sacral wing fracture		2	N/D
Left superior pubic ramus fracture		1	N/D
Right pubic root fracture		1	N/D
Pelvic hematoma		1	N/D
EXTREMITIES	EXTREMITIES		
N/D	N/D	N/D	N/D
TOTAL		13	10
Concordance 10/13 = 76.9%			

Patient 4			
PMCT Injuries	Autopsy Injuries	Number of PMCT Injuries	Number of Autopsy Injuries
HEAD AND FACE	HEAD AND FACE		
Diffuse subarachnoid hemorrhage	Massive bilateral subarachnoid hemorrhage	1	1
Bilateral intraventricular hemorrhage	Bilateral intraventricular hemorrhage	2	2
Diffuse cerebral edema			
	Right basal ganglia hemorrhage	N/D	1
	Midbrain hemorrhage	N/D	1
Bilateral parieto-occipital fracture	Bilateral parieto-occipital fracture	2	2
Open frontal sinus fracture	Comminuted left parietal fracture	1	1
Right temporal bone fracture	Base transverse temporal bone fracture	1	N/D
NDE fracture	Ethmoid fracture	1	1
Left I		1	N/D
Left II		1	N/D
	Left mandible fracture	1	N/D
Bilateral mandible condyle fracture	Left mandible fracture	2	1
	Left parasymphyeal mandible fracture	1	N/D
NECK	NECK		
N/D	N/D	N/D	N/D
CHEST	CHEST		
	Bilateral hemopneumothoraces	2	0
ABDOMEN/PELVIS	ABDOMEN/PELVIS		
N/D	N/D	N/D	N/D
EXTREMITIES	EXTREMITIES		
N/D	N/D	N/D	N/D
TOTAL		17	10
Concordance = 10/17 = 58.8%			

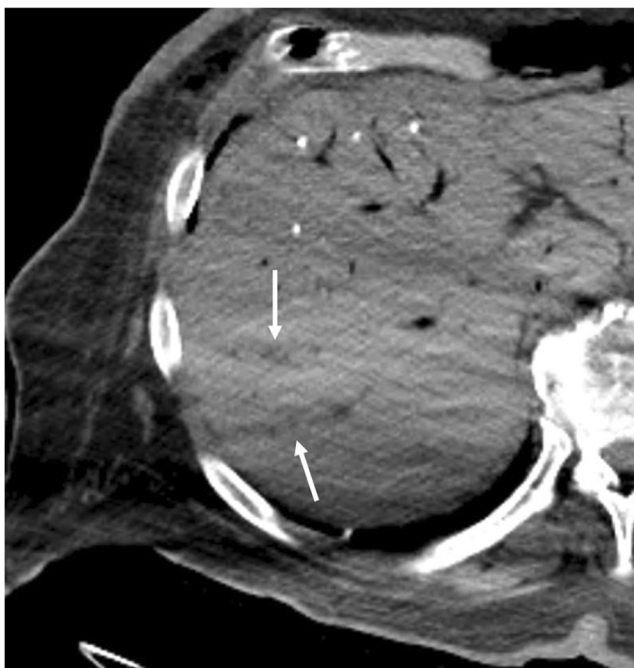


Fig. 1 Sixty-two-year-old male with right hepatic lobe lacerations. Axial PMCT image through the upper abdomen demonstrates subtle linear hypodensities (arrows) through the right hepatic lobe initially thought to be due to beam hardening artifact from the patient's adjacent arms. At autopsy, two right liver lacerations measuring 3.5 cm and 7 cm were identified in this region

device (such as a dual lumen laryngeal tube). A total of 18 individuals (47.4%) had at least one line or tube that was either malpositioned (in wrong location), suboptimally positioned (chest tube in a fissure), or both (Fig. 2). Ten patients (26.3%) had a malpositioned airway device ($N=3$ dual lumen laryngeal device folded above the vocal cords [Fig. 3], $N=4$ terminating above vocal cords, $N=2$ right mainstem, $N=3$ esophageal intubation [Fig. 4], $N=1$ left mainstem). A total of 23 patients (60.5%) had 29 intra-osseous catheters (IOC) in place, including 17 patients (44.7%) with 1 IOC and 6 patients

(15.8%) with 2 IOC. The most common location for an IOC was the proximal tibia ($N=14$ on the left and $N=8$ on the right). A total of 3 (10.3%) of the 29 IOC were malpositioned. The most common location for a malpositioned IOC was in the right shoulder (Fig. 4, $N=2$, 5.2% of the cohort, or 6.9% of IOC). A total of 13 patients (34.2%) had 22 large bore chest tubes (1 in 6 patients and 2 in 8 patients), all via a lateral approach. There were 12 chest tubes on the right (4 in major fissure, 2 at base, 4 in minor fissure, and 2 in posterior pleural space) and 10 on the left (3 in major fissure, 6 in the posterior pleural space, and 1 in the anterior pleural space). Of the 22 chest tubes, 11 were appropriately positioned in the anterior, posterior, or basilar pleural spaces, and 11 (50.0%) were suboptimally positioned in the fissures (4 on the right in the minor fissure, 4 on the right in the major fissure, and 3 in the left major fissure). None of the chest tubes were located outside of the thoracic cavity. A total of 3 patients (7.9%) had 7 needle thoracotomy (2 in 2 patients, and 3 in 1 patient), all of which were malpositioned ($N=6$ in chest wall [Fig. 5], $N=1$ in lung parenchyma). No needle thoracotomy was appropriately located in the pleural space at the time of PMCT.

Example: patient #1

Patient #1 was a 62-year-old male involved in a single motor vehicle collision (Table 1). He was ambulatory at the scene but then collapsed in traumatic arrest. The patient was resuscitated en route, and upon arrival, focused abdominal sonography in trauma (FAST) scan demonstrated no cardiac activity or pericardial effusion. Thoracotomy was immediately performed with full trauma resuscitation, including open cardiac massage and placement of a Foley catheter for massive transfusion directly into the heart. Despite these efforts, the patient was pronounced dead 20 min after arrival in the trauma bay. Injuries identified by physical examination at presentation included a vertical laceration with fragmentation of the nasal

Fig. 2 Support medical device misplacement based on post-mortem CT. IOC, intra-osseous catheter; CT, chest tube; ETT, endotracheal tube; NT, needle thoracotomy; VC, vocal cords

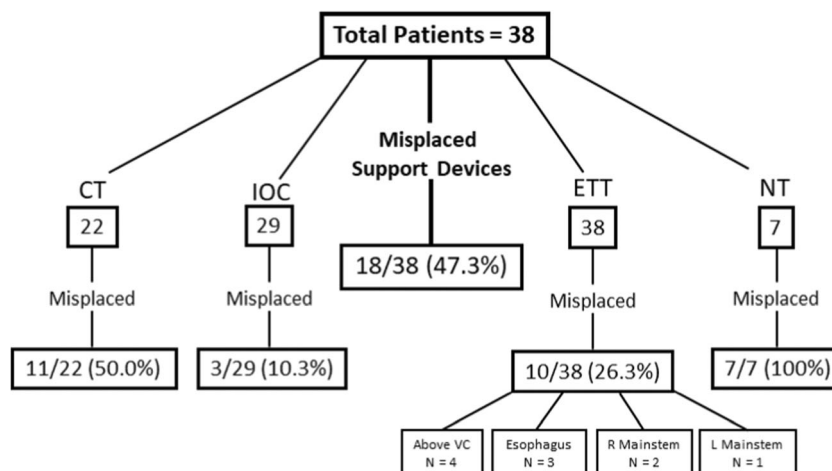




Fig. 3 Sixty-two-year-old male (same patient as in Fig. 1) with a malpositioned dual lumen airway device. Coronal CT demonstrates a dual lumen mechanical airway device with the oropharyngeal balloon (*) inflated in the hypopharynx. The esophageal balloon (arrow) is inflated above the vocal cords (arrow head) and is not appropriately positioned in the esophagus

bone and cartilage. The decedent's initial ISS based on physical exam findings was 1.

Post-mortem CT identified numerous additional injuries that were not suspected upon physical examination in the trauma bay, including the following:

- Multiple facial fractures (bilateral nasal, hard palate, and bilateral mandibular condyle with temporomandibular joint dislocation)
- Sternal fractures
- Multiple bilateral rib and costal cartilage fractures
- Anterior mediastinal hemorrhage with suspected aortic injury
- Bilateral hemopneumothoraces (large on right)
- Bilateral upper lobe pulmonary contusions
- Left acetabular fracture
- Left hip dislocation
- Left calcaneus
- Left talus fracture

In addition, there was a dual lumen airway device with the balloon inflated in the posterior oral cavity with tip terminating above the vocal cords (Fig. 3). Full formal autopsy was performed (Table 1), which in addition to the above findings, revealed hemorrhage of the left larynx and soft tissues near the cervical vertebrae and two right hepatic lobe lacerations (7 cm and 3.5 cm), which were not prospectively identified on PMCT. In retrospect, the right lobe liver lacerations are visible but partially obscured by beam hardening artifact due to the patients' adjacent arms (Fig. 1). The laryngeal and cervical hemorrhage was not visible, even in retrospect (not shown). The aorta was intact at autopsy. The ISS using the information from the PMCT scan was 75.

Discussion

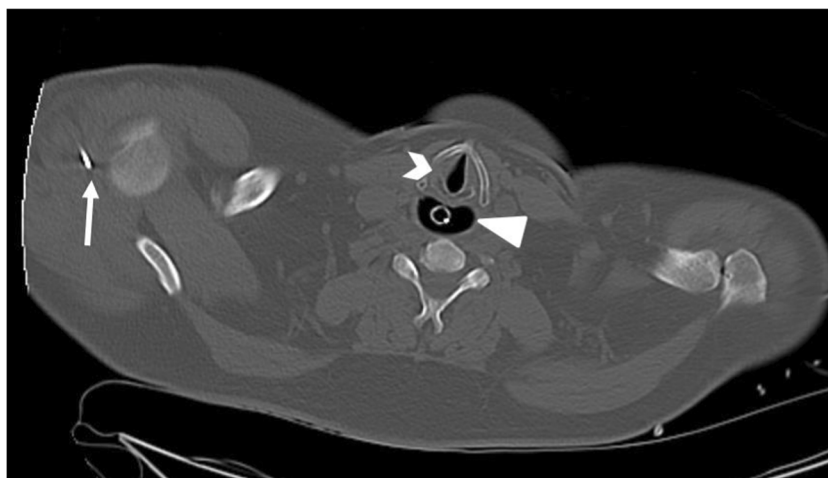
Autopsy remains the reference standard for post-mortem death investigation [4–6]. However, declining autopsy rates as well as personal, religious, or cultural objections for autopsy may lead some families to deny autopsy [4, 7]. As such, permission to perform a full clinical autopsy is often not provided, meaning that valuable information regarding the nature and extent of traumatic injuries and potential cause of death may be difficult or impossible to obtain, be misclassified, or lost all together [4, 8, 9]. A less invasive alternative is therefore desired.

Post-mortem radiological imaging has been utilized for over 100 years, but it has not been until relatively recently that computed tomography has been used as a part of death investigation [5, 10–15]. Post-mortem CT is a well-established means to identifying injuries or pathology not detected during autopsy or in lieu of formal full autopsy [4, 13, 14]. Existing literature suggests that PMCT is a useful adjunct to death investigation, though at this time, it cannot fully replace formal autopsy by a forensic pathologist [4, 14]. A meta-analysis published in 2009 comparing PMCT and formal autopsy for 244 victims in 15 studies found a wide concordance rate ranging from 46 to 100% [4].

PMCT versus formal autopsy

PMCT identified more injuries than autopsy alone. Excluding superficial soft tissue injuries (which may not be expected to be reliably identified on PMCT), there were a total of 80 distinct injuries or injury complexes (such as Le Fort fracture pattern, which was counted as one injury complex) in the 4 decedents on PMCT, and 56 distinct injuries or injury complexes on autopsy data (average 20 per decedent, range 13–35). The mean concordance rate of PMCT and autopsy for the cohort was 70.0% (Table 1), which is in the range of concordance described in the

Fig. 4 Forty-seven-year-old male with malpositioned endotracheal tube and intra-osseous catheter. Axial PMCT image through the lower neck/upper chest demonstrates esophageal intubation (arrow head). Right shoulder intra-osseous catheter (arrow) tip terminates in the shoulder musculature outside of the humeral head. Trachea = notched arrow head



literature [4]. Our results support what exists in the literature. However, unlike much of the previously published PMCT literature, our research focused on identifying injuries following accidental death with the purpose of determining a more accurate ISS above physical exam findings alone. In addition, we sought to determine the adequacy of emergently placed support medical devices, such as mechanical airways and pleural evaluation tubes, in the setting of accidental trauma. Though previous literature has addressed this, our study differs because our cohort was limited to blunt accidental death and in larger numbers than previously reported [16].

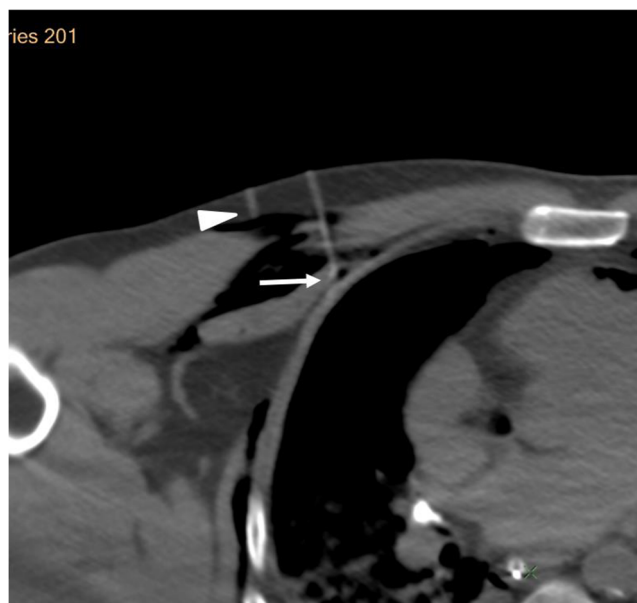


Fig. 5 Fifty-five-year-old male with malpositioned decompressive thoracotomy needles. Axial PMCT image through the mid chest focused on the right chest wall demonstrates two decompressive thoracostomy needles (arrow head and arrow) terminating outside of the pleural space in the deep chest wall musculature (arrow) and subcutaneous fat (arrow head)

Added value of PMCT—impact on ISS

In our study cohort, the mean ISS as determined by PMCT was substantially higher than ISS determined by physical exam alone (mean 50.3 vs 5.2). All patients who underwent PMCT had injuries that eluded detection by physical exam alone, and all patients had ISS that exceeded 21, indicating that all had a severe level of trauma. This information would have been lost in a vast majority of our cohort, as only 4 decedents (10.5%) underwent formal autopsy. As a result, PMCT helps to create a more complete trauma registry and can help explain trauma mortalities with a low ISS based on clinical information alone.

Added value of PMCT—lines and tube assessment

In our cohort, 18 decedents (47.3%) had a misplaced medical device. This is slightly higher than what exists for urgent intubations on individuals who initially survive, but lower than the existing PMCT literature on this topic. In a PMCT study from 2015 investigating the role of PMCT in the evaluation of support line placement, Lotan et al. reported that 14 out of 25 patients (56%) had misplaced support lines [16].

In our study, all decedents had mechanical airways in place, of which 10 (26.3%) were discovered to be malpositioned on PMCT. According to the American College of Radiology (ACR) appropriateness criteria, approximately 12–15% of endotracheal tubes are malpositioned after first attempt [17]. In the ICU setting, a study by Brunel et al. showed that in 219 patients, 14% of endotracheal tubes were malpositioned at first attempt [18]. A study by Katz et al., performed in an urban emergency medical service environment, 25% of endotracheal tubes were malpositioned, and of those, 67% were esophageal intubations and 33% were found to terminate above the vocal cords [19]. A study by Jemmett et al. in 2003

found that 12% of out-of-hospital endotracheal tubes were malpositioned, most commonly in the esophagus [20]. In the PMCT study by Lotan et al., a total of 8 out of 18 (44%) intubated decedents had malpositioned endotracheal tubes (3 in the right mainstem bronchus and 5 at or near the carina) [16]. Our results are in line with what is described in the literature.

Intra-osseous catheter placement is common in the setting of trauma or difficult vascular access, can be used to deliver high volumes of resuscitative fluids during the initial evaluation, and has a higher first placement success rate when compared to central venous catheters [21]. In our cohort, 23 decedents had 29 IOC placed, of which 10.3% were malpositioned on PMCT. In a prospective study on adults under active resuscitation in the emergency department, Leidel et al. showed that IOC is malpositioned 10% at first attempt [21]. Our results are concordant with this study.

Drainage of the pleural space with large bore chest tubes is one of the most common procedures performed on trauma patients. In a 2012 study of 1065 patients admitted to the emergency department, a total of 78% were optimally placed, with the remaining 22% suboptimally positioned (in a fissure or bent on itself) based on chest radiography or CT [22]. A study by Lotan et al. in 2015 showed that chest tubes are suboptimally positioned in 77% of PMCT scans, most commonly in the fissures [16]. In our study, a total of 13 patients had 22 large bore chest tubes in place during PMCT, including a total of 11 (50.0%) which were suboptimally placed in the fissures. Our results show a lower rate of suboptimally positioned chest tubes that is what described in the literature.

Decompressive needle thoracostomy (NT) is a well-known means of pre-hospital decompression of tension pneumothorax; however, it is not without controversy or risk [23]. Several series indicate that ineffective NT placement is the most common complication, with a failure rate of 22–50% [23]. A prospective case series of 108 major trauma patients with 114 NT demonstrated that only 2 (1.75%) were found to not penetrate the pleural space and were malpositioned in the chest soft tissues [24]. In a study published in 2010, needle length was found to be a factor in successful placement. Investigators found that only 4% of 4.5-cm NT failed to decompress the pleural space, compared to 65% of 3.2-cm NT [25]. In our study, a total of 3 patients had 7 needle thoracostomies placed, none of which were in the appropriate position on PMCT. The significance of this in our cohort is uncertain, as these needles are typically not secured in place. It is feasible that these needles could have been dislodged after placement or during patient transport.

The results of this analysis are being used for educational purposes for our trauma surgeons, emergency department providers, and community-based first responders.

Study limitations

We acknowledge several limitations of our study. First, this is a single-center study with a low autopsy rate of 10.5%. At our local coroner's office, it is customary for the forensic pathologist to elect to perform an "external examination only", which is determined at the time of body processing. Thus, a majority of the subjects did not undergo a full formal autopsy to confirm the findings seen on PMCT. As with other studies, our study showed that injuries may be missed or mischaracterized when compared to formal full autopsy [4, 6, 13, 26–30]. Comparing the PMCT and autopsy results is similar to those of previous studies, though the low number of formal autopsies limits our study. As previously reported, small intracranial blood collections may evade detection on PMCT [31]; thus, the ISS attributable to head injuries as determined by PMCT may have been underestimated. Secondly, the goal of our institutional PMCT program was to scan decedents who were unlikely to receive a full formal autopsy. Therefore, in theory, our selection criteria eliminated some decedents and limited the number of PMCT scans obtained. Thirdly, calculating the concordance between PMCT and autopsy proved difficult, as the concordance rate depends on the exact numbering and categorization of injuries. When possible, we counted single injuries as 1. However, this is more problematic for complex injuries as a part of the same injury pattern. For example, naso-orbito-ethmoid (NOE) fractures by their very nature include many fractures of many bones, but for the purposes of this report, which were counted as a single injury. Also, using this simplified quantification scheme, the number of injuries identified does not necessarily equate with injury severity. For example, 1 rib fracture would count the same as 1 liver injury, which may not contribute equally to the patients' overall mortality. In addition, some of the autopsy reports were not very specific with the degree of injury within a single organ, and thus the precise number of injuries for that organ could not be determined. Also, it is possible that the support medical devices, lines, and tubes could have been dislodged at any time during patient transport, with the positioning seen on PMCT not accurately reflecting their position at the time of trauma resuscitation. It is possible that at the time of PMCT, the decompressive needles could have been partially removed following large bore chest tube placement, resulting in the 100% malposition rate. Though not recorded, it is assumed that many of the decedents received chest compressions as a part of their resuscitation. Therefore, the rib fractures detected on PMCT may not have been the result of the initial traumatic event, thus artificially increasing the number of injuries identified. Lastly, the nature of the PMCT scan protocol is inherently non-contrast due to the subject's deceased state, which is known to limit detection of solid organ, vascular, and bowel injuries [4]. Some centers have used post-mortem CT angiography to evaluate for vascular injuries with

a great deal of success [32–35]; however, the equipment and expertise to carry out this type of study are not available at our institution.

In conclusion, we have found that PMCT is a non-invasive method to provide for a more complete and accurate trauma registry. We have shown that PMCT has added value in identifying unsuspected injuries that may be missed by physical exam and autopsy alone. Misplaced support medical devices are frequently identified on PMCT and can be used for medical provider educational purposes. Finally, other institutions with a low autopsy rate for trauma deaths may benefit from developing a PMCT program.

Compliance with ethical standards

Conflict of interest Scott D. Steenburg, MD

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