Forensic Imaging 20 (2020) 100349

Contents lists available at ScienceDirect

Forensic Imaging

journal homepage: www.sciencedirect.com/journal/forensic-imaging

Invited article

# Injury Detection in Traumatic Death: Postmortem Computed Tomography vs. Open Autopsy

Chatura Wijetunga[a,*], Chris O'Donnell[b], Tiffany Y So[a], Dinesh Varma[a,c], Peter Cameron[d,j], Michael Burke[b], Richard Bassed[b,g], Karen Smith[e,f,h], Ben Beck[i,j]

[a] Department of Radiology, Alfred Health, Melbourne, Australia
[b] Forensic Services, Victorian Institute of Forensic Medicine, Melbourne, Australia
[c] Department of Surgery, Monash University, Melbourne, Australia
[d] Emergency and Trauma Centre, Alfred Health, Melbourne Australia
[e] The Centre for Research and Evaluation, Ambulance Victoria, Australia
[f] Department of Community Emergency Health and Paramedic Practice, Monash University, Melbourne, Australia
[g] Department of Forensic Medicine, Monash University, Melbourne, Australia
[h] Department of Epidemiology and Preventive Medicine, Monash University, Melbourne, Australia
[i] Faculty of Medicine, Laval University, Quebec City, Quebec, Canada
[j] School of Public Health and Preventive Medicine, Monash University, Melbourne Australia

ARTICLE INFO

*Keywords:*
Post-mortem CT
Autopsy
Trauma
Forensic radiology
Injury
Abbreviated Injury Scale

ABSTRACT

*Objective:* To compare postmortem computed tomography (PMCT) vs. autopsy in detecting and analyzing injuries due to traumatic deaths.

*Materials and methods:* In this retrospective study, a cohort of 52 subjects were purposively sampled to reflect a broad range of injuries. Injuries from autopsy and PMCT reports were coded using the Abbreviated Injury Scale (AIS) and the level of agreement of AIS 2+ and 3+ injuries were compared.

*Results:* A combined total of 353 AIS-coded injuries were detected - PMCT detected 63% and autopsy detected 74% of injuries. PMCT identified 92 (26%) additional injuries missed by autopsy. PMCT missed 131 (37%) injuries. The kappa value for agreement between the two modalities for presence of injuries was moderate for the majority of anatomic regions [head ($\kappa = 0.53$), thoracic organs ($\kappa = 0.58$), upper extremity ($\kappa = 0.53$), pelvis ($\kappa = 0.45$), skeletal chest injuries ($\kappa = 0.57$)]. Kappa value was least among abdominal ($\kappa = 0.07$) and vascular injuries ($\kappa = 0.10$). Substantial agreement ($\kappa = 0.69$) was present in lower extremity injuries. PMCT outperformed autopsy for bony injuries, in particular, pelvic injuries, base of skull fractures and upper extremity injuries. PMCT better detected pneumothoraces. Soft tissue injuries, particularly abdominal organ injuries, lung contusions and vascular injuries were better detected by autopsy. When injuries missed by PMCT were reassessed, subtle but inconclusive imaging findings were identified.

*Conclusion:* A combination of PMCT and autopsy can detect more injuries than either modality in isolation. PMCT detected a considerable number of injuries missed by autopsy and vice versa.

## 1. Introduction

Autopsy is considered to be the cornerstone of forensic pathology, however, in the last few decades, autopsy rates across the world have suffered a gradual decline owing to a multitude of factors which include cultural, emotional and religious reasons [1–4]. In recent years, postmortem CT (PMCT) has emerged as a potential alternative to documenting and analyzing injuries in traumatic deaths.

Whilst multidetector CT imaging is considered indispensable in clinical trauma care, the importance of its role in post-mortem assessment is now beginning to be understood. Over the last decade, a number of studies have attempted to compare the two modalities. The majority of these have attempted to classify injuries under anatomic categories that are imprecise and often broadly defined (e.g.: “pulmonary wounds”, “solid organ wounds”, “gas in tissues or spaces”, “brain oedema”) [5–8]. This methodology may lead to erroneous linkage of different injuries within anatomic regions and can spuriously increase agreement between the two modalities. Furthermore, crucial

* Corresponding author at: Department of Radiology, Alfred Health, 55 Commercial Rd, Melbourne VIC 3004, Australia.
*E-mail address:* gihan.wijetunga@gmail.com (C. Wijetunga).

https://doi.org/10.1016/j.FRI.2019.100349
Received 11 August 2019; Received in revised form 31 October 2019; Accepted 2 November 2019
Available online 03 November 2019
2212-4780/ 

information about the severity of the injury can be lost in a simple binary analysis (e.g.: a small splenic laceration and a shattered spleen are both splenic injuries but with very different prognoses) and may hinder an understanding of the profile of injury and cause of death. Therefore, to establish PMCT as an effective diagnostic tool vis-à-vis autopsy, a robust injury classification system must be used.

To this effect, the aim of this study was to determine the concordance between PMCT and autopsy by classifying injuries in a specific nature using the Abbreviated Injury Scale (AIS) - an anatomically-based consensus-derived injury scoring system that classifies each injury by body region according to its relative importance on a 6-point ordinal scale [9]. A small number of studies have used this methodology and have begun to identify the strengths and weaknesses of each modality [10–12]. Of these, some have been limited by small sample sizes [10,12] and others have focused on how well PMCT and autopsy capture the severity of given injuries [11].

To the best of our knowledge, this is the first Australian study to quantitatively compare the performance of PMCT vs. autopsy in detecting injuries in deaths due to trauma.

## 2. Materials and methods

### 2.1. Study design

We conducted a retrospective review of a sample of prehospital trauma deaths that were attended by Ambulance Victoria over the period of 2008–2014. The current study forms a sub-study of a wider program of research investigating prehospital trauma deaths [13].

### 2.2. Data sources

As described previously [13], prehospital trauma deaths were identified in the Victorian Ambulance Cardiac Arrest Registry (VACAR) and linked to data from the National Coronial Information System (NCIS). The NCIS is an internet database of all deaths resulting from injury or non-natural causes in Australia and New Zealand. In our jurisdiction, a coroner is responsible for making a determination about whether a full autopsy (complete internal and external examination) is required, or if an external examination alone is sufficient to establish a cause of death. Under the Coroners Act 2008 [14], the wishes of the senior next of kin must be taken into consideration regarding the decision to undertake an autopsy and the senior next of kin has the right to decline an autopsy being performed. The NCIS contains case identifiers that enabled linkage to PMCT data from the Victorian Institute of Forensic Medicine (VIFM).

### 2.3. Case identification

A sample of 52 prehospital trauma deaths that had undergone a full autopsy were included in this study. To ensure a variety of injury types are captured, we purposely sampled from patients in one of six main injury groups with cases randomly selected from within each of these groups that were identified a priori: head ($n = 8$), spinal ($n = 8$), thoracic ($n = 8$), abdominal ($n = 8$), extremity ($n = 10$) and vascular ($n = 10$) injuries. Patients may have sustained injuries to other body regions in addition to the aforementioned six main injury groups.

### 2.4. Autopsy

Autopsy was performed without prior formalin fixation, using the modified Rokitansky technique i.e. en-block organ removal from tongue to prostate or cervix. Autopsies were performed by a variety of practitioners including forensic pathologists, pathology trainees and visiting fellows under the supervision of a forensic pathologist, the extent of the post-mortem examination determined by a coroner. At the completion of the medico-legal examination a report is prepared for the coroner to assist him/her, if possible, to determine the cause of death. PMCT images were available for viewing to forensic pathologists conducting autopsy. As they were not expert readers of PMCT imaging, a radiologist was available for consultation for particularly difficult cases. Formal PMCT reports were written after autopsy and were not available to pathologists.

### 2.5. Post-mortem CT

All deceased persons were scanned within 24 h after pronunciation of death and usually less than 12 h after death. CT was performed on a Siemens SOMATOM® Definition Flash scanner without intravenous contrast. Full-body (vertex to feet) PMCT protocol parameters were 120 kVp tube voltage, effective mAs of 280, pitch of 0.6, tube rotation time of 0.55 s with a field of view of 500 mm. Image reconstruction slice thickness was 1.5 mm using a B30f medium smooth reconstruction kernel. At our institution, bony structures outside the head and neck are assessed by windowing of B30f kernel images. PMCT of the head and neck (vertex to sternal notch) was performed at a tube voltage of 120 kVp, effective mAs of 420, pitch of 0.55, rotation time of 1 s with a field of view of 300 mm. Image reconstruction slices were 1.0 mm in thickness using a H31s medium smooth and H70h very sharp reconstruction kernels. Images were viewed on syngo.via software VB20A_HF05 (February 2017) and reformatted as necessary at the time of reporting.

Post-mortem CT review was conducted by 2 senior radiology trainees who had 4–5 years' experience in clinical trauma imaging at a major trauma centre in Melbourne, Victoria but had little prior experience in PMCT. The trainees were given tutorials focusing on death artifact by an experienced senior forensic radiologist prior to and during reporting of the 52 cases, and any uncertain findings were resolved by consultation with the senior forensic radiologist. The radiologists did not have access to the pathology reports and were only given a police report of the case at the time of reporting which provided a brief account of the circumstances surrounding the death.

### 2.6. Injury coding

All injuries were coded using the Abbreviated Injury Scale (AIS) 2005 (2008 update) [9]. Coding of autopsy-reported and PMCT-reported injuries was conducted independently by clinical coders who were accredited in AIS coding.

For the purposes of this study, injuries were classified as follows:

- Head – intracranial injury (AIS 3+ intracranial injury)
- Head – skull fracture (AIS 2+ skull fracture)
- Thoracic organ injury (AIS 3+ injury to thoracic organs)
- Skeletal chest injury (AIS 2+ injury to the rib cage)
- Abdominal organ injury (AIS 3+ injury to abdominal organs)
- Upper extremity injury (any amputation, AIS 3+ crush injury, AIS 2+ clavicle, scapula, humerus, ulna or radius fracture)
- Lower extremity injury (any amputation, AIS 3+ crush injury, AIS 2+ femur, tibia or fibula fracture, or hip or knee joint dislocation)
- Pelvis injury (AIS 3+ injury to the pelvis)
- Vascular injury (AIS 3+ vascular injury)

Further sub-classifications of these injury groupings are reported in the Results section.

### 2.7. Statistical analysis

Injuries identified on PMCT were compared against those identified on autopsy using Cohen's Kappa Statistic. The Kappa statistic was interpreted as poor ($\kappa$ = 0.00–0.20), fair ($\kappa$ = 0.21–0.40), moderate ($\kappa$ = 0.41–0.60), substantial ($\kappa$ = 0.61–0.80) and almost perfect ($\kappa$ = 0.81–1.00).

Ten cases were independently reviewed by both radiologists to quantify inter-reader reliability. Similarly, inter-reader reliability was measured using Cohen's Kappa statistic. Data analysis was performed using Stata (Version 14.2, StataCorp, College Station, TX).

### 2.8. Ethical approval

The present study was approved by the Victorian Department of Justice and Regulation HREC (CF/16/272), the Monash University HREC (CF16/532 – 2016000259) and the Victorian Institute of Forensic Medicine Ethics Committee (EC 20/2016).

## 3. Results

This investigation included 52 cases. The median age was 50 years (quartile 1: 29 years; quartile 3: 60 years), and most patients were male ($n$ = 39; 75%), sustained blunt trauma ($n$ = 48; 94%) and were involved in transport-related events ($n$ = 38; 75%). Across both PMCT and autopsy, a total of 353 AIS-coded injuries were detected. These were present in the following anatomic regions: head injury ($n$ = 62, 18%), abdominal organ injury ($n$ = 30, 8%), thoracic organ injury ($n$ = 97, 27%), skeletal chest injury ($n$ = 40, 11%), upper extremity ($n$ = 45, 13%), lower extremity ($n$ = 26, 7%), pelvis ($n$ = 21, 6%), vascular injury ($n$ = 32, 9%). The vast majority of injuries were identified in the thorax (137, 39%). Pelvic injuries (6%) were the least frequent.

Of the pooled total injuries, PMCT detected 222/353 (63%) and autopsy detected 261/353 (74%) injuries. In addition to the 130 (37%) injuries identified on both autopsy and PMCT, a further 92 (26%) injuries were detected by PMCT alone. Autopsy detected 131 injuries (37%) which PMCT failed to identify.

Kappa statistic was considered moderate for the presence of any head injury (κ = 0.53, 95% confidence interval (CI): 0.29,0.77), however Kappa values were lower for specific head injury types, with the exception of vault fractures (Table 1). Thoracic organ injuries showed moderate agreement (κ = 0.58, CI: 0.32,0.84) and this was reflected in moderate agreement amongst the individual thoracic injury types with the exception of lung injuries for which the kappa statistic was poor. Moderate agreement was also seen among upper extremity injuries (κ = 0.53, CI: 0.30,0.75) with the exception of scapular injuries for which agreement was poor. Kappa values were also moderate for pelvic injuries (κ = 0.45, CI: 0.23,0.68) and skeletal chest injuries (κ = 0.57, CI: 0.30,0.85). PMCT and autopsy showed least agreement in abdominal organ injuries (κ = 0.07, CI: −0.07,0.21) and vascular injuries (κ = 0.10, CI: −0.03,0.23). On the other hand, agreement was substantial among lower extremity injuries (κ = 0.69, CI: 0.49,0.89) and of these the highest agreement was seen among femoral injuries (κ = 0.92, CI: 0.77,1.00).

### 3.1. Injuries detected by PMCT and missed on autopsy

Anatomic regions where PMCT notably outperformed autopsy include pelvis (12 additional injuries, κ = 0.45, CI: 0.23, 0.68), base of skull fractures (9 additional injuries, κ = 0.40, CI: 0.13,0.67), haemopneumothoraces (7, κ = 0.56, CI: 0.30,0.82), upper extremity injuries (40, κ = 0.53, CI: 0.30,0.75). Although haemopneumothoraces have been grouped together for purposes of analysis, further review demonstrated PMCT had identified 27 pneumothoraces missed on autopsy. The anatomic region in which the most numerous injuries detected by PMCT and missed on autopsy was in the upper extremity. Thirty additional injuries were identified in this region by PMCT. Of these, 13 were scapular fractures (κ = 0.10, CI: −0.08,0.28).

### 3.2. Injuries detected by autopsy and missed on PMCT

Soft tissue injuries were near consistently better detected by autopsy. Seven brainstem injuries (κ = 0.19, CI: −0.13,0.52), 9 cerebral contusions (κ = 0.15, CI: −0.11,0.41) and all 16 abdominal organ injuries were missed on PMCT and detected by autopsy. In the thorax, 20 lung contusions (κ = 0.06, CI: −0.14,0.26) and 11 hemopericardia/heart injuries (κ = 0.41, CI: 0.16,0.66) were identified on autopsy that were missed by PMCT. The vast majority of vascular injuries (20 or 91%, κ = 0.10, CI: −0.03,0.23) were detected on autopsy alone and only 2 of these matched by PMCT. Two further injuries, a thoracic aortic injury and a femoral arterial injury were identified on PMCT alone.

Imaging of the injuries that were missed on PMCT and detected on autopsy were retrospectively re-analyzed. Of the 7 brainstem injuries, review of imaging of 2 cases demonstrated auxiliary findings that could raise suspicion of a brainstem injury however the parenchymal injury itself could not be visualized. In one case, this was extensive subarachnoid haemorrhage and in the other, there was a displaced clival fracture adjacent to the pons. In the remaining 5 cases, the injury was entirely occult on PMCT predominantly due to beam hardening artifact and poor signal-to-noise ratio.

Nine subdural hemorrhages (SDH) were only detected on autopsy and missed on PMCT (κ = 0.12, CI: −0.18,0.42). One of these cases demonstrated an extradural haemorrhage crossing over the midline falx on PMCT which autopsy had most likely mistaken for a SDH. In the remaining cases, no SDH were confidently identified on PMCT.

Of the 3 base of skull fractures identified on autopsy and missed on PMCT, careful review of 2 cases revealed that although the injury was correctly identified by the radiologist, this had not been coded as such due to wording of the report. In the final case, no base of skull fracture could be identified on imaging review.

Twenty lung injuries were missed on PMCT and were detected by autopsy (κ = 0.06, CI: −0.14,0.26). Reviewing the imaging of 6 cases revealed pulmonary contusions in the form of non-specific airspace changes, though it was difficult to differentiate these from atelectasis and aspiration. In another case, pulmonary injury could be inferred from depressed rib fractures (this was interpreted as haemothorax instead of pulmonary contusion). No parenchymal lung injuries were evident in the remaining 12 cases.

Two diaphragmatic injuries were identified on autopsy and missed on PMCT (κ = 0.55, CI: 0.16,0.94). Imaging review demonstrated retrocrural hematoma in one case. In the other, small volume gas was present in the peritoneum co-existing with pneumothoraces. In the absence of an identifiable hollow viscus injury, a diaphragmatic injury could be inferred. Interestingly, PMCT was able to identify 2 diaphragmatic ruptures, of which, one was described by autopsy as a "diaphragm laceration" and the other was missed.

Despite careful review, the 11 heart injuries/hemopericardia identified by autopsy could not be visualized on PMCT. Of the 5 kidney injuries identified on autopsy, some perinephric fat stranding or retroperitoneal hematoma could be retrospectively appreciated on PMCT in 4 cases. Similarly, in 4 of the 5 splenic injuries detected on autopsy, perisplenic stranding was present. Autopsy identified 11 liver injuries, missed on PMCT. Imaging review of one of these cases demonstrated hemoperitoneum and sentinel clot overlying the liver capsule. In another case, the radiologist had raised suspicion of a liver injury based on surrounding hematoma. In the remaining 9 cases, no evidence of a liver injury was identified. In all of the above, the parenchymal injury itself could not be directly visualized, as would be expected for CT performed without intravenous contrast.

Autopsy identified 2 radial/ulnar injuries (κ = 0.45, CI: 0.11,0.79), not recorded on PMCT, of which, one was outside the scan field and the other had been missed during reporting. A knee dislocation was recorded by autopsy however on PMCT, only a fibular fracture could be identified and the knee remained enlocated.

As stated in the methodology, this study focuses on AIS 2–3+ injuries. A sensitivity analysis was performed using AIS 4+ injuries (Table 4) and can be viewed in the electronic supplementary material. Also included in the supplementary material is the level of agreement

**Table 1**
Level of agreement between CT and Autopsy on the presence or absence of injury.

| Type of injury | Injury present CT only | AU only | CT and AU | % Agreement | Kappa | 95% CI |
|---|---|---|---|---|---|---|
| Head injury | | | | | | |
| Any | 6 (21.4%) | 5 (17.9%) | 17 (60.7%) | 76.6% | 0.53 | 0.29–0.77 |
| Brainstem | – | 7 (87.5%) | 1 (12.5%) | 85.1% | 0.19 | −0.13–0.52 |
| Subdural | 3 (21.4%) | 9 (64.3%) | 2 (14.3%) | 74.5% | 0.12 | −0.18–0.42 |
| Extradural | 1 (33.3%) | 2 (66.7%) | 0 (0%) | 93.6% | −0.03 | −0.09–0.03 |
| Diffuse axonal injury | – | – | – | – | – | – |
| Subarachnoid | – | 1 (100%) | – | – | – | – |
| Intraventricular | – | 1 (100%) | – | – | – | – |
| Intracerebral | 1 (100%) | – | – | – | – | – |
| Contusion | – | 9 (90%) | 1 (10%) | 80.9% | 0.15 | −0.11–0.41 |
| Base of skull fracture | 9 (45%) | 3 (15%) | 8 (40%) | 74.5% | 0.40 | 0.13–0.67 |
| Vault fracture | – | 1 (25%) | 3 (75%) | 97.9% | 0.85 | −0.55–1.00 |
| Abdominal organ injury | | | | | | |
| Any | – | 16 (94.1%) | 1 (5.9%) | 66.0% | 0.07 | −0.07–0.21 |
| Bladder | – | 2 (100%) | – | 95.7% | 0.00 | – |
| Duodenum | – | 1 (100%) | – | 97.9% | 0.00 | – |
| Kidney | – | 5 (100%) | – | 89.4% | 0.00 | – |
| Liver | – | 11 (100%) | – | 76.6% | 0.00 | – |
| Pancreas | – | – | – | – | – | – |
| Rectum | – | – | – | – | – | – |
| Spleen | – | 5 (100%) | – | 89.4% | 0.00 | – |
| Stomach | – | 1 (100%) | – | 97.9% | 0.00 | – |
| Other | 1 (20%) | 4 (80%) | – | 89.4% | –0.04 | −0.11–0.3 |
| Thoracic organ injury | | | | | | |
| Any | 3 (9.1%) | – | 30 (90.9%) | 83.0% | 0.58 | 0.32–0.84 |
| Bronchus | – | – | – | – | – | – |
| Diaphragm | 2 (28.6%) | 2 (28.6%) | 3 (42.8%) | 91.5% | 0.55 | 0.16–0.94 |
| Esophagus | – | – | – | – | – | – |
| Lung | 3 (10.7%) | 20 (71.4%) | 5 (17.9%) | 51.1% | 0.06 | −0.14–0.26 |
| Heart / Haemopericardium | – | 11 (64.7%) | 6 (35.3%) | 76.6% | 0.41 | 0.16–0.66 |
| Haemothorax / Pneumothorax / Haemopneumothorax | 7 (17.9%) | 1 (2.6%) | 31 (79.5%) | 83.0% | 0.56 | 0.30–0.82 |
| Trachea | – | – | – | – | – | – |
| Other | 6 (100%) | – | – | 87.2% | 0.00 | – |
| Skeletal chest injury | | | | | | |
| Any | 5 (12.5%) | 2 (5.0%) | 33 (82.5%) | 85.1% | 0.57 | 0.30–0.85 |
| Upper extremity injury | | | | | | |
| Any | 10 (41.7%) | 1 (4.2%) | 13 (54.1%) | 76.6% | 0.53 | 0.30–0.75 |
| Amputation | – | – | – | – | – | – |
| Crush | – | – | – | – | – | – |
| Clavicle | 6 (66.7%) | – | 3 (33.3%) | 87.2% | 0.45 | 0.10–0.79 |
| Scapula | 13 (92.9%) | – | 1 (7.1%) | 72.3% | 0.10 | −0.08–0.28 |
| Humerus | 6 (54.5%) | – | 5 (45.5%) | 87.2% | 0.56 | 0.27–0.86 |
| Ulna-radius | 5 (45.5%) | 2 (18.2%) | 4 (36.4%) | 85.1% | 0.45 | 0.11–0.79 |
| Lower extremity injury | | | | | | |
| Any | 7 (33.3%) | – | 14 (66.7%) | 85.1% | 0.69 | 0.49–0.89 |
| Amputation | – | – | – | – | – | – |
| Crush | – | – | – | – | – | – |
| Femur | 1 (12.5%) | – | 7 (87.5%) | 97.9% | 0.92 | 0.77–1.00 |
| Tibia-fibula | 9 (52.9%) | – | 8 (47.1%) | 59.1% | 0.53 | 0.29–0.78 |
| Hip dislocation | – | – | – | – | – | – |
| Knee dislocation | – | 1 (100%) | – | 97.9% | 0.00 | – |
| Pelvis injury | | | | | | |
| Any | 12 (57.1%) | – | 9 (42.9%) | 74.5% | 0.45 | 0.23–0.68 |
| Pelvic ring | 12 (57.1%) | – | 9 (42.9%) | 74.5% | 0.45 | 0.23–0.68 |
| Acetabulum | – | – | – | – | – | – |
| Vascular injury | | | | | | |
| Any | – | 20 (90.9%) | 2 (9.1%) | 57.5% | 0.10 | −0.03–0.23 |
| Carotid | – | – | – | – | – | – |
| Vertebral artery | – | – | – | – | – | – |
| Jugular vein | – | 1 (100%) | – | – | – | – |
| Aorta thoracic | 1 (5.3%) | 18 (19.7%) | – | 59.6% | −0.04 | −0.12–0.04 |
| Brachiocephalic artery | – | – | – | – | – | – |
| Coronary artery | – | – | – | – | – | – |
| Pulmonary artery | – | 1 (100%) | – | – | – | – |
| Subclavian artery | – | – | – | – | – | – |
| Thoracic artery (other) | – | – | – | – | – | – |
| Brachiocephalic vein | – | – | – | – | – | – |
| Pulmonary vein | – | 3 (100%) | – | 93.6% | 0.00 | – |
| Subclavian vein | – | – | – | – | – | – |
| Vena cava thorax | – | 2 (100%) | – | 95.7% | 0.00 | – |
| Thoracic vein (other) | – | – | – | – | – | – |
| Aorta abdominal | – | 2 (100%) | – | 95.7% | 0.00 | – |
| Celiac artery | – | – | – | – | – | – |

(*continued on next page*)

**Table 1** (*continued*)

| Type of injury | Injury present CT only | AU only | CT and AU | % Agreement | Kappa | 95% CI |
|---|---|---|---|---|---|---|
| Iliac artery | – | – | – | – | – | – |
| Mesenteric artery | – | – | – | – | – | – |
| Abdominal artery (other) | – | 1 (100%) | – | – | – | – |
| Iliac vein | – | – | – | – | – | – |
| Vena cava abdominal | – | 1 (100%) | – | – | – | – |
| Abdominal vein (other) | – | – | – | – | – | – |
| Axillary artery | – | – | – | – | – | – |
| Axillary vein | – | – | – | – | – | – |
| Brachial artery | – | – | – | – | – | – |
| Brachial vein | – | – | – | – | – | – |
| Upper artery (other) | – | – | – | – | – | – |
| Upper vein (other) | – | – | – | – | – | – |
| Femoral artery | 1 (100%) | – | – | – | – | – |
| Femoral vein | – | 1 (100%) | – | – | – | – |
| Popliteal artery | – | – | – | – | – | – |
| Popliteal vein | – | – | – | – | – | – |
| Lower artery (other) | – | – | – | – | – | – |
| Lower vein (other) | – | – | – | – | – | – |

between PMCT and autopsy-derived AIS scores for a given injury detected by both modalities (Table 2). Inter-reader reliability between the two radiologists interpreting PMCT (Table 3) is also shown.

## 4. Discussion

Our study compares the performance of PMCT against autopsy in detecting and characterizing injuries in 52 individuals who died following trauma. Overall, PMCT and autopsy demonstrated moderate agreement for injuries under the major anatomic regions of head injury, thoracic organ injury, skeletal chest injury, upper extremity injury, lower extremity injury and pelvic injury. Correlation was very low for abdominal organ injury and vascular injury reflecting the superiority of autopsy in detecting these types of injuries. On the other hand, PMCT demonstrated superiority in detecting bony injuries and abnormal gas accumulations.

The use of PMCT in this small cohort allowed an additional 92 injuries to be identified. As mentioned before, the vast majority of these were osseous injuries including skull fractures, pelvic fractures and other skeletal bony injuries. Fracture diagnoses in difficult to reach sites are seldom made on autopsy and can be easily evaluated on PMCT [7,15]. Of the 2 radius/ulna injuries identified on autopsy and missed on PMCT, one was missed by the reporting radiologist and the second was not in the field of view of the scan. A considerable number of injuries under the category of hemothorax/pneumothorax/hemopneumothorax were detected by PMCT alone and the majority of these were pneumothoraces. The superiority of PMCT in detecting gas in anatomic cavities and in evaluating bony injuries has been previously described [6,7,10–12]. This is not surprising - for autopsy to successfully detect gas collections, such as tension pneumothorax or pneumoperitoneum, special autopsy techniques such as under-water dissection must be utilized which are not routinely performed.

We performed a detailed analysis of injuries identified on autopsy but missed on PMCT. Interestingly, in several body regions, where autopsy had indicated an injury, auxiliary findings could be identified retrospectively on PMCT. This was particularly the case for intra-abdominal organ injuries involving the kidneys and spleen where retroperitoneal fluid or perisplenic fluid could be detected. In 11 liver injuries identified by autopsy, in all but 2 cases, there were no imaging features to suggest an underlying liver injury, most likely relating to the small size of such injuries [12,16]. The limitation of PMCT in detecting organ injuries has been observed previously [10–12,17] and more than likely relates to the fact that imaging has been performed without contrast. Leth et al. [11], demonstrated higher detection rates for solid organ injuries by PMCT than our study and this could reflect their use of a trained forensic radiographer and their practice of scanning each body region separately which may have led to better image quality. This may have allowed more subtle injuries to be identified by PMCT.

Similarly, in the majority of cardiac injuries and parenchymal brain/brainstem injuries there were no features of injury identifiable on PMCT. In cases where autopsy identified lung injuries, some cases demonstrated non-specific airspace changes on PMCT which were often indistinguishable from aspiration, atelectasis or decomposition [18], a limitation that has been described previously [15]. The vast majority of vascular injuries including 18 aortic injuries were occult on PMCT [6,11,12]. This is unsurprising as vessels appear collapsed, at times demonstrating post-mortem changes - making detection nearly impossible of all but intramural hematoma and transection of a vessel.The literature indicates PMCT angiography (PMCTA) substantially improves the detection of traumatic vascular injury [19–21] but this is not a routine procedure at our institution for trauma cases. Our experience in PMCTA is predominately in cases of non-traumatic hemorrhage or fatal bleeding after medical intervention. Thus, we believe standard PMCT should not be used as a substitute for autopsy but as a necessary adjunct, as proposed by several others [10,11,22].

In contrast to previous studies which claim PMCT as good as or better than autopsy in identifying extra-axial brain hemorrhages [7,11], in our study, a considerable number of subdural hemorrhages were only detected on autopsy, similar to other reports [6,8]. On retrospective review of the imaging, one case demonstrated an extradural hematoma (see below) and 2 cases demonstrated thin, subtle subdural densities which would have been easily missed on initial reporting. In the remaining 6 cases, no subdural blood could be identified. The cause for this is unclear but could be due to artifact obscuring small volume haemorrhage. Development of subdural blood after CT scanning has also been theorized [17].

Using autopsy as the gold standard against which PMCT is measured is problematic [11,17]. We found several instances in our study where autopsy identified injuries which should have been easy to corroborate on PMCT. A knee dislocation was described on autopsy, however imaging demonstrated a fibular fracture and an enlocated, intact knee joint. In another case, subdural blood was described in the autopsy report however PMCT demonstrated an extradural hematoma at the skull vertex crossing the midline over the falx, not described at autopsy. In a third case, a base of skull fracture was described on autopsy but the skull base was intact on imaging. Although this study describes many injuries that are discordant between PMCT and autopsy, the aforementioned cases are remarkable in that they represent false positives of autopsy. Similarly, PMCT may have also reported false positives which would be impossible to refute as the bodies have since been destroyed.

## 5. Limitations

Our study contained several limitations which must be taken into account when interpreting these results. The sample size of 52 subjects was moderate for this type of study, however the sample size was too small to assess inter-reader variability and level of agreement between AIS-coded injuries.

A major limitation of this study is the pathologists who prepare the autopsy report were not blinded to the CT images at the time of autopsy. Though not expertly trained in radiology, the pathologists would view the CT images briefly whilst conducting the autopsy. Occasionally in complex cases, the pathologists would consult a radiologist to help interpret imaging. This suggests autopsy reports may have been contaminated with information from CT or pathologists may have been led to assess a specific body region based on CT findings, which they otherwise may have missed. Despite this potential advantage to autopsy, a considerable number of additional injuries were detected by PMCT alone.

Depending on the terminology used in autopsy and PMCT reports, the same injuries may have been AIS-coded in different ways adding to the level of discordance. For example, during the initial analysis, pneumothoraces, haemothoraces and haemopneumothoraces were coded as separate injuries before being combined under one injury group for analysis purposes. Similarly if rib fractures were not quantified and merely described (for example, when there is extensive rib cage injury) a different AIS coding would apply, creating discordance.

It is also important to note that unlike the PMCT reports which were purpose-written for this research paper, the autopsies were conducted as part of routine practice and were retrospectively analysed, similar to other studies [7,8,10]. In the setting of widespread injuries and due to time constraints of routine practice, the level of description of the injuries may have been truncated, thus affecting the level of AIS coding of the autopsy-detected injuries.

Prospective studies which make use of standardized forms allowing the radiologist and pathologist to directly select AIS injury scores rather than reporting in free-form should mitigate these challenges in the future.

Furthermore, both spinal and facial injuries have been omitted from analysis in this study. Previous studies have demonstrated superiority of PMCT in detecting injuries in these regions [8,12] as would be expected for osseous injury and anecdotally this appears to be the case in this study also.

PMCT images in our study were interpreted by clinical radiology trainees whose principal place of practice was a major trauma centre in Melbourne. They had 4–5 years of clinical trauma radiology experience but had limited training in forensic radiology. Despite exposure to trauma radiology, clinical radiologists may be unfamiliar with injuries that are incompatible with life [17]. The bulk of reporting body CT in clinical radiology would consist of contrast enhanced imaging whereas the majority of forensic radiologists' caseload would consist of unenhanced imaging in which, subtle findings must be given greater emphasis for certain injuries to be suspected. For these reasons, it is likely that PMCT would have been more accurate if read by experienced forensic radiologists.

Other reasons for PMCT underperforming relative to autopsy may relate to image quality and scan technique. Scanning in the arms down position, for example, introduces artifact over the abdominal organs and chest which can limit assessment. To mitigate this, in clinical trauma radiology, the head and neck would be scanned arms down and chest/abdomen scanned with arms up. Lack of formal radiography training in PMCT technicians could also negatively impact on image quality.

Some of these factors may explain the inconsistent performance of PMCT and autopsy as described in different studies.

## 6. Conclusion

This is the first Australian study to quantitatively compare PMCT vs. autopsy for detecting injuries in persons dying from trauma. Our study found an overall moderate correlation between autopsy and PMCT for the presence of the majority of AIS-coded injuries. If relied on autopsy alone, a considerable number of injuries would be missed which would have been apparent on PMCT. This study supports previous reports in finding PMCT better at detecting bony injuries and abnormal gas accumulations in anatomic cavities. Autopsy outperformed PMCT at detecting soft tissue and vascular injuries as has been documented previously. Injuries initially missed by PMCT and detected by autopsy demonstrated many subtle but inconclusive findings on re-assessment of PMCT imaging. The two modalities appear complimentary to each other, both demonstrating inherent strengths and weaknesses. Rather than a substitute, we advocate the use of PMCT as an adjunct to autopsy.

## Funding

This project was funded by the RACV Safety Research Fund, the Victorian State Government Department of Health and Human Services, the Royal Australasian College of Surgeons (RACS) Foundation of Surgery and the Australian Resuscitation Council (Victorian Branch).

Ben Beck was supported by an Australian Research Council Discovery Early Career Researcher Award Fellowship (DE180100825). Peter Cameron was supported by a National Health and Medical Research Council (NHMRC) Practitioner Fellowship (#545926).

## Declaration of Competing Interest

The authors declare that they have no conflict of interest.

## Acknowledgements

The National Coronial Information System and the Victorian Institute of Forensic Medicine are thanked for their assistance.

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.FRI.2019.100349.

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