Utility of Postmortem X-ray Computed Tomography (CT) in Supplanting or Supplementing Medicolegal Autopsies

Final Technical Report

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Abstract

The utility of advanced radiologic imaging technology (computed tomography and magnetic resonance imaging) in the practice of forensic pathology has not been clearly defined. A variety of case studies have indicated potential areas of use such as trauma, foreign body discovery, mass fatality processing and body identification. However, systematic studies have been few. There has been inconsistent evidence of the utility of post-mortem computed tomography (PMCT) as a substitute for autopsy in cases of fatal trauma. Some studies have shown that there are injuries seen by PMCT that are not detected by autopsy, indicating that PMCT is likely useful as an autopsy adjunct. Previously performed studies were limited by small study populations, large variation in postmortem interval, differences in study protocols, differences in who interpreted the scans and how injuries were scored.

Over four years, we utilized a large, centralized statewide medical examiner office which serves a population of 2 million people and conducts 2100 autopsies per year to prospectively evaluate four potential situations where PMCT might supplant or supplement forensic autopsy. We evaluated 174 blunt force injury deaths, 205 firearm deaths, 65 pediatric (5 years and younger) trauma deaths, and 460 drug poisoning deaths from June 2011 through December 2013, performing a full autopsy and complete PMCT on each decedent, with the attending pathologist blinded to PMCT results and the attending radiologist blinded to autopsy findings. Autopsy and PMCT reports were coded by an Abbreviated Injury Scale (AIS)-certified coder. Injuries detected and described by autopsy and PMCT were compared in consensus conferences attended by radiologists and pathologists who had not been involved in the original cases. Conference attendees decided if each injury was a match between autopsy and PMCT, a category 1 miss (should have been seen but was not) or a category 2 miss (was not seen but would not expect to see it given location/resolution.) All data were entered into Excel and analyzed by SAS 9.2.

Continuous variables were compared using either student's t-test or Wilcoxon rank sum test, and categorical variables were compared using chi square or Fisher exact tests. Kappa statistics were calculated to assess inter-observer agreement for maximal AIS (MAIS) scores by region. Total numbers of injuries, as well as numbers of matched injuries and category 1 and 2 injuries for autopsy and PMCT were calculated and compared.

There was strong agreement between autopsy and PMCT in assigning cause of death. In 85% of blunt force injury deaths, 99.5% of firearm fatalities, and 81.4% of pediatric trauma deaths, the cause of death assigned by PMCT was determined to be correct and the same as that assigned by autopsy. In drug poisoning deaths, agreement between cause of death ranged from 34.2% to 77.9% by line of the death certificate, with significantly less agreement in people over the age of 40. PMCT detected more injuries than autopsy in the blunt force and firearm cohorts, but autopsy detected more in pediatric trauma and drug poisoning cohorts. Percentages of findings coded as matches ranged from 38.4% for drug poisoning deaths to 64.9% in firearm fatalities. Sensitivity for PMCT ranged from 61.2% in the pediatric cohort to 83.6% for multiple gunshot wounds, and autopsy sensitivity ranged from 71.3% in pediatric trauma deaths to 84.2% in single gunshot wound deaths. The best agreement for MAIS scores was in firearm fatalities, with substantial agreement in the head and chest and moderate agreement in the abdomen and extremities. The percentage of unique injuries seen on autopsy which should have been detected on PMCT but were not ranged from 15.2% for the firearm fatalities to 33% in the pediatric trauma deaths. The percentages of injuries seen on PMCT but missed on autopsy and should have been detected were very comparable between the blunt force injury and pediatric trauma deaths (21.2% and 21.5%, respectively). Sensitivity ranged from 61.2% for PMCT in pediatric trauma deaths to 84.2% for autopsy in single gunshot wound fatalities. PMCT accurately

assessed numbers of gunshot wounds up to three wounds, but became less accurate for more than three wounds. Comparison of autopsy to PMCT revealed neither modality is perfect, but both independently allow correct assessment of severity of injuries and cause of death.

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Executive Summary

Traumatic injuries reflecting homicidal, suicidal and unintentional circumstances and suicidal and unintentional poisoning are very common causes of death in cases evaluated by the medicolegal death investigative system. The Centers for Disease Control and Prevention (CDC) estimate over 50,000 deaths each year result from violent trauma. The evaluation of these cases usually involves an investigation of the circumstances surrounding the death, an autopsy conducted by a pathologist, and laboratory testing such as toxicologic evaluations. The findings from these investigations are used to generate conclusions about the cause and manner of death. The medicolegal death investigation system supports public safety, criminal justice and public health systems.

In order to determine if there are specific circumstances where postmortem computed tomography (PMCT) can supplant or supplement conventional autopsies, we used a high-volume statewide medical examiner's office (New Mexico Office of the Medical Investigator- OMI) to prospectively evaluate four potential situations where PMCT might supplant or supplement forensic autopsy. We analyzed common unnatural death subsets (blunt force and firearm injuries in individuals older than 5 years, and all poisoning deaths) and the less common subset of traumatic deaths in children 5 years of age and younger.

Prior to the beginning of each autopsy day, all OMI autopsy cases underwent a full body PMCT scan performed by a board-certified CT radiologic technologist. All bodies requiring autopsy were scanned due to circumstantial information at the time of death often being inadequate to know whether a case would potentially fit one of our four analysis subsets because of occult findings. PMCT scans from cases that fell outside of the four study subsets were archived as a registry for future studies.

Following the scan, cases received standard forensic autopsies, including examination of the skull and brain and toxicologic evaluations. Potential cases to be included in the study were identified by the supervising radiologic technologist from the day's docket (a list of incoming cases and their circumstances). Any potential cases were flagged for follow-up to ensure they met cohort inclusion criteria once cause and manner of death were determined by the case pathologist. Cases were assigned NIJ study numbers, one for pathology/autopsy and a different one for radiology, with the linkage to OMI case numbers maintained by the supervising radiologic technologist.

University of New Mexico (UNM) board-certified radiologists with the appropriate subspecialty training and experience interpreted all PMCT scans. A core team of four radiologists reviewed most cases. However, two subspecialty-trained pediatric radiologists interpreted cases in the pediatric subset and a neuroradiologist read the head and neck portions of the non-pediatric studies. For all cases, radiologists were provided with the same investigative and circumstantial information before interpreting the PMCT scan that was available to the case forensic pathologist prior to autopsy. The radiologists were blinded to the autopsy findings prior to evaluating the PMCT scans, and pathologists were blinded to all PMCT scans.

The radiologists completed a standard dictation from the PMCT scan and then determined a cause of death (disease or injury that initiates the fatal sequence of events) based on the investigative information and the PMCT findings. Their completed dictations were sent electronically to an Abbreviated Injury Scale (AIS)-certified coder, who entered both a text description and its associated AIS score for each injury recorded in the radiology report. The coder entered all scores and text descriptions into a Research Electronic Data Capture (REDCap) database.

The autopsy pathologists described the autopsy findings and determined a cause of death using the circumstantial information and autopsy findings as per routine protocols. These findings were entered in the usual format into the OMI electronic medical examiner record, and the case was assigned a unique NIJ autopsy number, different from the NIJ radiology number for the same case. After redacting the OMI case number (to blind the AIS coder to any association with the radiology report for that same case), the OMI autopsy report was sent electronically to the AIS coder.

Following entry of the blinded autopsy and PMCT findings into the REDCap database, the autopsy and PMCT AIS-scored injuries were exported as an Excel spreadsheet and the cases matched on the original OMI case number, with the linkage to NIJ study numbers maintained by the supervising radiologic technologist. Autopsy and PMCT injuries, organized by the six AIS regions (head, face, chest, abdomen, extremities, external) were arrayed vertically, side-by-side for each decedent. These completed cases were reviewed in a consensus conference by a study pathologist and a study radiologist (neither of whom was involved in the original autopsy or PMCT interpretation) to determine which PMCT injuries were confirmed by autopsy (a match, coded by M with the number of the match for that decedent), which PMCT injuries were not seen at autopsy (coded A1), which injuries were seen at autopsy but not on PMCT (R1), which PMCT injuries were in a region not evaluated by autopsy (A2) and which autopsy injuries not seen on PMCT and were beyond the resolution of the scanner (R2). A data set of total injuries (those seen only at autopsy + those seen only on PMCT + those seen on both autopsy and PMCT) was established. The combined team of radiologists and pathologists also reached consensus on the cause of death, determining if the cause of death from the autopsy was correct, if the one from PMCT was correct, or if both were correct or incorrect. For the drug poisoning

deaths, a reviewing pathologist not associated with the original autopsy reviewed the case using the investigative information including scene photographs, PMCT report, external examination findings (but no visceral autopsy results) and the toxicology report and determined the cause of death based on the this information set.

Data from the consensus conferences were abstracted into Excel spreadsheets and analyzed using SAS version 9.2. Percent agreement was calculated for cause of death statements, and comparisons of mean numbers of injuries detected were calculated. We compared maximal AIS (MAIS) scores by calculating kappa statistics between autopsy and PMCT for each AIS region: head, face, chest, abdomen, extremities and external. Injury Severity Scores (ISS, the sum of squares of the highest AIS scores in three different body regions) between the radiology results and the forensic pathology results were categorized by percentage of cases where the PMCT scores were equal to the autopsy scores, greater than autopsy scores, and less than autopsy scores. Sensitivity was calculated using the total number of matched findings as the true positives, and A1 and R1 findings as the relevant false negatives.

We evaluated 174 blunt force injury deaths, 205 firearm deaths, 65 pediatric (5 years and younger) trauma deaths, and 460 drug poisoning deaths from June 2011 through December 2013. Across all four cohorts of this study, blunt force injury, firearm fatalities, pediatric trauma and drug poisoning deaths, it was evident that both autopsy and PMCT can separately arrive at the same cause of death for given decedent. In 85% of blunt force injury deaths, 99.5% of firearm fatalities, 81.4% of pediatric trauma deaths, and up to 78% of drug poisoning deaths, the cause of death assigned by PMCT was determined to be correct and the same as that assigned by autopsy. In most, but not all, of the cases where the cause of death did not match between autopsy and

PMCT, the autopsy cause of death was assessed as the correct one, in 10% of blunt force injury deaths, 1.5% of firearm fatalities and 17% of pediatric trauma deaths.

For each decedent, the most severe injury by region was abstracted and recorded as the maximal AIS score. Comparing these scores for each decedent by region (MAIS assigned by PMCT compared to MAIS assigned by autopsy) found mostly moderate to substantial agreement between the two techniques, depending on region. Understandably, as radiologists were not able to perform an external examination, the least amount of agreement between autopsy and PMCT occurred in the external region, with kappa values ranging from 0.03 for firearm fatalities to 0.2 for pediatric trauma deaths in regard to the external region. The best agreement for MAIS scores was seen in the firearm fatalities, with substantial agreement in the head and chest and moderate agreement in the abdomen and extremities. Lower levels of agreement were seen in the blunt force, drug poisoning, and pediatric trauma deaths, with only fair agreement in the head and abdomen and moderate agreement in the chest. The poorest MAIS agreement was seen in the drug poisoning deaths.

Looking at numbers of injuries detected, PMCT detected significantly more injuries than autopsy in both the blunt force injuries and the firearm fatalities arms of the studies, though autopsy detected more injuries than PMCT in the pediatric trauma and drug poisoning arms, the two cohorts with the most cases where no traumatic injuries were present. The percentage of injuries coded to be a match between autopsy and PMCT was 46.6% for blunt force deaths, 38.4% for drug poisoning deaths, and 41.7% for pediatric trauma deaths, but 64.9% for firearm fatalities. The percentage of unique injuries seen on autopsy which should have been detected on PMCT but were not ranged from 15.2% for the firearm fatalities to 33% in the pediatric trauma deaths. The percentages of injuries which were ruled to be below the imaging resolution of the

CT scan ranged from 6.2% of unique injuries in the blunt force deaths to 30.7% in drug poisoning deaths. The percentages of injuries seen on PMCT but missed on autopsy and should have been detected were very comparable between the blunt force injury and pediatric trauma deaths (21.2% and 21.5%, respectively). The percentage was lower for firearm fatalities (16.8%) and drug poisonings. The percentage of injuries seen on PMCT but determined to be outside the routinely dissected areas of an autopsy was highest in the blunt force injury deaths (19.1%), followed by drug poisoning deaths (15.4%) and lower for both the pediatric trauma and firearm fatalities (7.4% and 9%, respectively).

When assessing how well PMCT functions in assessing firearm fatalities, there was excellent agreement in both cause of death determination and MAIS scores. Radiology detected up to three gunshot wounds with 100% accuracy, and correctly identified the entry wound in 91% of all single gunshot wound fatalities. The exit wound was correctly identified in 91% of the deaths where there was a discrete entry wound (excluding those cases where a shotgun was used, resulting in a large part of the head or body missing rather than a single exit wound). In one case, the exit wound identified by PMCT was determined to be the correct exit, rather than the one identified on autopsy. PMCT also performed respectably when assessing a bullet's trajectory through the body, correctly identifying the up/down axis in 79% of single gunshot wound fatalities, the front/back axis in 72% of single GSW deaths, and the left/right axis in 85% of single GSW cases. Assessment of re-entry of a single bullet was more difficult, but could only be evaluated in two of the deaths. Even in multiple gunshot wound deaths (where the decedent suffered from two to eight separate gunshot wounds), 64% of the findings were a match between autopsy and PMCT, and MAIS scores indicated fair (head, face) to substantial (chest, abdomen) agreement by region. The wound parameters were more challenging to assess with multiple,

intersecting injury tracts, but PMCT correctly identified entry wounds 68% of the time, and exit wounds 64% of the time. Trajectories were more challenging to assess with the multiple wounds, with only 44%-58% correctly identified. With multiple gunshot wounds, it would be difficult to adequately describe the trajectories, and not advisable to supplant autopsy with PMCT. In single gunshot wounds, PMCT performed well and could be used to assess entry and exit wounds. Further information would be needed to improve the determination of trajectory, but this could also be a factor of inexperience on the radiologists' part, as they have not had the training and experience in trajectory determination of the forensic pathologists.

Reviewing the types of injuries most commonly missed by autopsy and PMCT, the most commonly missed findings on autopsy, which in the opinion of the reviewing consensus physicians should have been detected, are very similar between blunt force, firearm and pediatric trauma deaths. Cerebral intraventricular hemorrhage was the finding most often seen on PMCT which was either not found or not noted on autopsy across all three types of death. Other hemorrhages were frequently among the missed findings, including subdural and subarchnoid hemorrhages, and facial fractures and cerebral edema were also among the ten most commonly missed PMCT findings, similar to previous studies. Other commonly missed PMCT findings not seen on autopsy included gas accumulations such as pneumothorax and pneumocephalus and vertebral body fractures, which were determined to be out of the scope of routine autopsies. Not surprisingly, external contusions and lacerations were the most commonly missed finding on PMCT across these three cohorts, but the most common radiology misses also included hemothoraces, lung and liver lacerations and atlanto-occipital dislocations.

The picture for the drug poisoning deaths for missed findings differed substantially from the previous three cohorts. In these deaths, autopsy most frequently missed calcifications, both

intracranial and in coronary arteries, fractures, nephrolithiasis and aspirations. Radiology most frequently missed external contusions, as in the previous cohorts, but then missed obesity, pulmonary edema, cirrhosis and atherosclerosis. With very few acute injuries and a significant incidence of natural disease, drug poisoning deaths are challenging for approaching as PMCT-only. Deaths that present initially as potential drug poisoning are often ultimately attributed to natural disease or an interplay between natural disease and drugs, especially in people over the age of 40, where the prevalence of natural disease can create challenges in determining cause of death. Nevertheless, in this age group, pathologists using PMCT and scene investigation data correctly identified the cause of death in 74.7% of the deaths. In decedents under the age of 40, the use of PMCT without information from the internal examination done at autopsy resulted in 86% correct cause of death determinations, a figure similar to the blunt force injury and pediatric trauma cohorts.

It is apparent that in all four types of deaths studied, both autopsy and PMCT missed injuries. Sensitivity was respectable but not perfect for either technique, ranging from a low of 61.2% for radiology in pediatric trauma deaths to a high of 84.2% for autopsy in single gunshot wounds. Neither one was perfect in detecting all injuries present in a decedent, challenging the long-held belief of autopsy as the gold standard for injury detection. Ideally, both techniques would be used in tandem, particularly in suspected cases of child abuse, where a full cataloging of injuries is imperative. Given the high percentages of agreement in cause of death determination, and moderate to substantial agreement in assessment of injury severity both by region and overall, PMCT could be used to supplant autopsy, particularly if a full external examination is completed in concert with a rigorous PMCT interpretation by a radiologist familiar with post-mortem scans.

In an ideal world, all medical examiners would have access to not only a CT scanner, but an experienced radiologist to interpret the results from the scans for them. Our results indicate that autopsy misses injuries that can only be seen on PMCT for 17% to 21% of all injuries in decedents whose deaths are due to firearm fatalities, pediatric trauma or blunt force injuries. In a small but not-non-existent percentage of studied cases (1.5%-3.6%), the autopsy-assigned cause of death was found to be incorrect, a finding that would not have been revealed without the information from the PMCT and a review of the case by a panel of study pathologists and radiologists. In the majority of cases included in this study, PMCT, when paired with a thorough external examination, could supplant autopsy and would be of particular value in cases of family, religious or cultural objections.

I. Introduction

1. Statement of the problem

Traumatic injuries reflecting homicidal, suicidal and unintentional circumstances and suicidal and unintentional poisoning are very common causes of death in cases evaluated by the medicolegal death investigative system. The Centers for Disease Control and Prevention (CDC) estimate over 50,000 deaths each year result from violent trauma (1). The evaluation of these cases usually involves an investigation of the circumstances surrounding the death, an autopsy conducted by a pathologist, and laboratory testing such as toxicologic evaluations. The findings from these investigations are used to generate conclusions about the cause and manner of death (2). The medicolegal death investigation system supports public safety, criminal justice and public health systems.

Autopsies in deaths falling under the jurisdiction of the medicolegal death investigative system should be performed by physicians certified in forensic pathology by the American Board of Pathology (3). Unfortunately, these physicians are in short supply, with approximately 400 in practice across the US (4). There are presently not enough forensic pathologists to meet the national death investigative needs (4). Additionally, for quality purposes, inspection and accreditation standards for the practice of forensic pathology require medicolegal death investigative offices to staff their offices so that forensic pathologists do not perform more than 250 autopsies per year (5). Because of manpower and staffing issues, many offices do not meet this standard (6). Autopsies are expensive and time-consuming procedures. The use of postmortem advanced imaging technology such as X-ray computed tomography (CT) and magnetic resonance imaging (MRI) could potentially reduce the numbers of forensic autopsies performed and enhance the information provided when autopsies are conducted (3, 7). Consequently, the National Academy of Sciences has recommended that the implementation of

advanced imaging technology, as a component of medicolegal death investigation, be further studied (3).

In recent years, a few low-volume European forensic pathology centers and one US center (Armed Forces Institute of Pathology) have identified potential applications for postmortem imaging technology (CT and MRI) through the use of case reports and case series (7). These small studies provided inconsistent evidence about the reliability of postmortem CT (PMCT) in recognizing injuries and identifying the cause of death (8). Without a validation of the accuracy and utility of imaging technologies in forensic pathology through scientific studies associated with autopsy findings, they cannot be used independently (9). A high-volume, centralized, statewide medical examiner's office is needed to prospectively evaluate situations where CT might supplement, or even supplant, forensic autopsies.

If there are circumstances where PMCT can supplant autopsy, medicolegal death investigative jurisdictions might be able to achieve a cost savings by reducing autopsy numbers. Additionally, medical examiners and coroners (ME/C) might be able to follow a family's desire to avoid an autopsy if diagnostic information, sufficient to render an accurate evaluation of the condition of the body and determination of the cause of death, can be developed through imaging. Autopsies also clearly pose occupational hazards for prosectors, and by utilizing PMCT to supplant a fraction of autopsies, these occupational risks can potentially be decreased. If PMCT can supplant autopsy in certain situations or if there are situations where PMCT provides important supplemental information to autopsy, then local, state and federal funding sources can prioritize building this capacity in ME/C offices.

2. Literature Review

Wilhelm Röntgen developed the process of x-ray in 1895. Shortly thereafter, in the same year, the procedure was used in its first forensic application to locate projectiles in a shooting victim. Other forensic applications were quickly recognized (e.g., skeletal trauma and identification) and the technology became widely used in both clinical forensic medicine and forensic pathology (10). Today, it is the rare medical examiner office that does not make daily use of this technology. X-ray computed tomography (CT) was developed as the progeny of the x-ray in 1972 and underwent rapid transition from the scanning of successive single axial slices to the continuous scanning of complete volumes at high resolution (spiral/helical CT) over the succeeding decades (11, 12). Despite widespread use of advanced imaging technology in clinical medicine that allows for a three-dimensional perspective, its utility in forensic pathology was not considered until 1996, when investigators at the University of New Mexico (UNM) evaluated the utility of postmortem cranial MRI in cases of suspected child abuse (13). After 2000, European forensic pathology centers began to evaluate the utility of PMCT and MRI for forensic autopsy and called the process "Virtopsy" (14). These low-volume European centers have identified many potential applications for advanced imaging technology in forensic pathology through the use of case reports and case series.

The utility of advanced imaging technology in the practice of forensic pathology is not clearly defined (15). A variety of case studies and case series indicate potential areas of use, including trauma (firearm, blunt force, drowning, burns, strangulation), foreign body discovery, mass fatality processing and body identification (15-30). However, systematic studies are few (8, 31). A study that looked at the sensitivity of antemortem CT scans performed within 24 hours of death concluded that the technology was inadequate in detecting trauma (31). However,

this study focused on blunt injury and was limited by the scans which were performed at intervals up to one centimeter (cm) and might not have had the resolution necessary to be of value in a forensic setting. Also, this study did not evaluate the utility of PMCT in determining the cause of death and or as an adjunct to autopsy. A meta-analysis that looked at the value of PMCT as an alternative for autopsy in trauma victims reviewed 15 studies that included 244 victims (8). The authors found inconsistent evidence of the utility of PMCT as a substitute for autopsy in cases of fatal trauma. The percentage of agreement on the cause of death found by PMCT compared with autopsy in this analysis ranged from 46-100%. Most of the studies reviewed in this meta-analysis detected large numbers of injuries by PMCT not seen by autopsy, indicating that PMCT is likely useful as an autopsy adjunct. This study was limited by a large variation in postmortem interval, differences in study protocols including a wide range of CT parameters, including slice thickness, differences in who interpreted the scans (radiologists vs. pathologists) and how injuries were scored. These authors recommended the development of a large study with a uniform protocol using the Abbreviated Injury Scale.

The Abbreviated Injury Scale (AIS) is a universally accepted anatomical scoring system that standardizes injury terminology and provides researchers with a simple numerical score for ranking and comparing injuries by severity (32). The AIS assigns to injuries a severity value ranging from 1 (minor) for trivial wounds, to 6 (maximum) for uniformly fatal wounds (32). This is in addition to the six-digit AIS code indicating region of the body affected, anatomic structure involved, and level of injury. Injury Severity Scores (ISS) were developed to incorporate the concept that the combined effect of multiple wounds of lesser severity, occurring in different body regions, can have a combined lethality (32). The ISS for each case derives from the sum of the squares of the three highest (maximal) AIS scores and is used as a

retrospective predictor of mortality. The AIS system is a valuable tool recommended for forensic documentation of traumatic injuries (33) and has been used successfully in previous PMCT-autopsy comparative studies (34, 35).

Postmortem imaging of blunt force injuries

Fatal blunt force injuries can be accidental, homicidal, or suicidal in nature. Blunt force injuries comprised 25% of autopsies performed in 2013 at the New Mexico Office of the Medical Investigator (OMI) and 58% of these deaths involved motor vehicle crashes (36). Autopsies of these cases, particularly crash victims, utilize significant resources, as most blunt force injury cases require a complete autopsy to determine the extent and severity of injuries, as well as the presence or absence of natural disease. The autopsy findings, as well as the scene investigation, are used to determine cause and manner of death.

A limited number of small studies have been performed to evaluate PMCT in determining the extent and severity of traumatic injuries as compared to autopsy. One study with 52 traffic fatalities that used the AIS system found 94% agreement between autopsy and PMCT findings (34). The areas of lowest agreement involved the facial bones, neck organs, lungs, kidneys and gastrointestinal tract. PMCT did not easily detect aortic lacerations. If PMCT can accurately and reliably identify significant blunt force injuries, it would allow ME/Cs to forego performing autopsies in some of these cases and divert resources to other needs. Furthermore, if PMCT is shown to be more sensitive in identifying a unique subset of injuries, it may prove to be a valuable supplement to autopsy. PMCT has been previously shown to be more sensitive than autopsy in identifying some injuries such facial fractures, gas embolism, and other small air collections (8).

Postmortem imaging of firearm injuries

There have been several case studies and case series that have explored the utility of PMCT imaging of gunshot wound victims (15-17, 29, 37-39). These studies suggest that PMCT adds value to autopsy and some suggest that PMCT could replace forensic autopsy in selected cases. A case report of a suicidal gunshot wound of the head emphasized the speed of CT scanning time and the efficacy of providing rapid, objective, non-invasive and non-destructive documentation of the wound (17).

Only 2 series of gunshot wound cases with PMCT are reported (15, 16, 29). A study of eight cases (seven gunshot wounds of the head and one gunshot wound of the torso) concluded that PMCT provided a number of advantages over autopsy (16). In particular, PMCT provided a three dimensional demonstration of the wound, allowing for more exact bullet localization for retrieval. In head injury cases, PMCT allowed for localization of bone fragments and consequently was able to distinguish entrance from exit wounds. PMCT also showed potential for visualization of gunshot residue in and under the skin, determining the exact size of the bullet, and drawing conclusions about ammunition type. Finally, PMCT provided permanent documentation for independent observer evaluation and was judged excellent for courtroom presentations, forensic reports and teaching. The disadvantages of PMCT compared to conventional autopsy included an inability to adequately document superficial injuries and the lack of color discrimination.

The other series included 13 military victims shot with high-velocity weapons (15, 29). In one report of these cases, the authors compared PMCT to digital x-rays (29). Another report with these cases compared PMCT to autopsy (15). These studies were compromised by an average postmortem interval of 3.5 days, allowing for decompositional changes to interfere with

PMCT interpretations. When compared to x-ray, PMCT more precisely determined the location of bullet fragments, a prominent feature of high-powered rifle wounds, and more accurately assessed organ injuries and wound tracks. When compared with autopsy, PMCT was able to identify subtle fractures not easily identified at autopsy and was able to precisely identify small bullet fragments that might be difficult to locate at autopsy. However, with cases of multiple gunshot wounds with intersecting paths, PMCT led to an underestimation of the number of wounds. Furthermore, non-contrasted PMCT was poor at identifying vascular injury and the sources of blood collections. In this study the radiologists reading the PMCT scans were blinded to the autopsy results, but it was not clear whether the pathologists were blinded to the radiology results. In addition to documenting bony defects in gunshot cases, PMCT is believed to be good at identifying hematomas, fluid collections and gas collections, but poor at differentiation between organs and vascular structures (39). Prior to this funded study, there has not been a large study of typical gunshot victims from a US civilian population that compared PMCT with forensic autopsy.

Postmortem imaging of childhood traumatic fatalities

Postmortem radiologic imaging of children has long been used to detect injuries, particularly in fatalities suspected to be from abuse. Traditionally, the postmortem imaging has been confined to X-rays because ME/Cs lacked access to other imaging techniques (40). However, antemortem CT and MRI imaging of abused or otherwise injured children who survive in a hospital before succumbing to their injuries has been utilized by forensic pathologists to direct their examinations (41). Little is known about using PMCT or post-mortem MRI in children in addition to x-ray. A comparison of postmortem cranial MRI and autopsy findings in 11 infants who died unexpectedly or from suspected abuse concluded that postmortem MRI was

helpful in guiding the attention of the pathologist to specific areas of focal cerebral abnormality (14). Prior to this funded study, there has not yet been a large study of pediatric cases including abusive trauma where postmortem imaging, particularly CT, has been compared to autopsy findings.

Postmortem imaging of drug poisoning deaths

Poisoning deaths make up a large fraction of medicolegal autopsies and can represent suicidal, accidental, and homicidal circumstances. These deaths have been steadily increasing in incidence in New Mexico, largely due to prescription opioid abuse and increasing suicide rates (1, 42, 43). In New Mexico, poisoning deaths comprised 24.9% of the 2013 OMI autopsies (36).

Poisoning is usually suspected because of circumstantial information (e.g., history of drug abuse, depression or suicidal intent) and death scene findings (e.g., presence of a syringe, prescription bottles). Professional practice standards indicate that autopsies should be performed in these cases to exclude competing causes of death (trauma or disease) and to identify underlying diseases that can influence the interpretation of toxicologic findings (44). Toxicologic analyses are key to determining the cause of death. However, the toxicological findings need to be evaluated in the context of the autopsy findings, as sometimes individuals with underlying severe natural diseases die from what would be characterized as "sublethal" drug concentrations.

The use of PMCT to evaluate drug poisoning deaths has not been previously explored. If PMCT can reliably exclude injuries and identify underlying natural disease conditions in potential poisoning deaths such that the combination of external examination, PMCT and toxicologic evaluation accurately identifies the cause of death, it will be possible for ME/C offices to effectuate significant cost savings by not performing autopsies. In addition, some

subsets of drug poisoning deaths (e.g., intravenous drug abusers) have a high prevalence of bloodborne infections such as human immunodeficiency virus (HIV) and hepatitis C (HCV) (45, 46). These infections pose a risk of occupational transmission to autopsy prosectors that have been calculated to be as high as 2.4% for HIV and 39% for HCV during a forensic pathologist's career (10). Reducing the numbers of autopsies of individuals with these bloodborne infections can reduce the risk of occupational transmission of these diseases.

3. Statement of hypotheses:

Blunt Force Injuries: Can a PMCT scan supplant autopsy in recognizing fatal blunt force injuries and identifying the cause of death? If not, does PMCT recognize sufficient injuries not recognized by autopsy to justify its utility as a supplemental procedure?

1. *Hypothesis*: In fatalities from blunt force injuries, PMCT can recognize fatal blunt force injuries and identify the cause of death so that it can be used to supplant autopsy in certain situations (e.g., motor vehicle collisions).
2. *Hypothesis*: In situations where a robust categorization of injuries is important (e.g., blunt force homicide) PMCT will identify sufficient skeletal and soft tissue injuries outside the scope of standard autopsy to justify its utility as an adjunct procedure.

Firearm Injuries: Can a PMCT scan supplant autopsy in recognizing fatal gunshot wound tracks and trajectories? If not, does PMCT recognize sufficient gunshot injuries not recognized by autopsy to justify its supplemental utility?

1. *Hypothesis*: PMCT will recognize fatal gunshot wound tracks and trajectories in cases with single gunshot wounds or multiple gunshot wounds with non-intersecting paths so that it can be used to supplant autopsy. In cases of multiple gunshot wounds with intersecting paths PMCT will not provide information sufficient to supplant autopsy.
2. *Hypothesis:* In cases of multiple gunshot wounds with intersecting paths, PMCT will not identify sufficient gunshot injuries to justify its utility as a supplemental procedure.

Childhood traumatic fatalities: Does the combination of autopsy + PMCT scan supplement the injuries identified by the present practice of autopsy + x-ray in childhood injury deaths? Does the addition of PMCT to the standard practice of autopsy + x-ray in childhood injury deaths change the cause of death determination?

1. *Hypothesis*: Autopsy + PMCT will identify significantly more injuries in these cases than the present practice of autopsy + x-ray but will not change the cause of death.

Drug Poisoning Deaths: In potential cases of drug poisoning, will the combination of external body examination + PMCT scan + toxicologic evaluation recognize enough underlying natural disease and traumatic injuries to supplant autopsy + toxicologic evaluation in correctly identifying the cause of death?

1. *Hypothesis*: External body examination + PMCT scan + toxicologic evaluation will recognize underlying natural disease and traumatic injuries sufficient to supplant the standard practice of autopsy + toxicologic evaluation in correctly identifying the cause of death, in individuals less than 40 years of age where the prevalence of natural disease is low. The combination of external body examination + PMCT scan + toxicologic evaluation will not recognize underlying natural disease enough to supplant the standard practice of autopsy + toxicologic evaluation in correctly identifying the cause of death in individuals greater than 40 years of age where the prevalence of diseases not visible by PMCT (e.g., coronary atherosclerosis) is higher.

II. Research Design and Methods

We used a high volume statewide medical examiner office (New Mexico Office of the Medical Investigator) to prospectively evaluate four potential situations where PMCT might supplant or supplement forensic autopsy. We analyzed common unnatural death subsets (blunt force and firearm injuries in individuals older than 5 years, and all poisoning deaths) and the less common subset of traumatic deaths in children 5 years of age and younger.

The Office of the Medical Investigator (OMI) is the statewide, centralized medical examiner agency for New Mexico (2014 population: 2,085,572 million (47)) that is located within the University of New Mexico (UNM) School of Medicine (SOM). This agency investigates all sudden, suspicious or unexplained deaths and annually performs approximately 2100 full autopsy examinations in the centralized facility. The agency employs 8 board-certified forensic pathologists.

In September 2010 OMI moved into a new facility (61,000 gross sq ft) that includes a biosafety level 3 (BSL 3) autopsy space with 16 autopsy stations and separate suites for both CT and MR imaging (48). The CT imaging suite contains a Philips Brilliance Big Bore 16 slice CT scanner. This scanner accommodates subjects weighing up to 650 pounds and has a large gantry (85 cm) to facilitate scanning subjects with large body habitus. The facility is also equipped with analog portable x-ray equipment (AMX-4 GE and Picker) with Philips PCR Eleva S, Computed Radiography (CR) reader and FUJI CR cassettes for digital capture of radiologic images. The MRI scanner, a Siemens Magnetom 1.5 T Sonata Maestro Class, was installed in August 2011.

Prior to the beginning of each autopsy day, all OMI autopsy cases underwent a full body PMCT scan performed by an American Registry of Radiologic Technologists (ARRT) board-certified CT radiologic technologist. All bodies requiring autopsy were scanned due to

circumstantial information at the time of death often being inadequate to know whether a case would potentially fit one of our four analysis subsets (e.g., pediatric trauma, drug poisoning, blunt trauma such as subdural hematomas). PMCT scans from cases that fell outside of the four study subsets were archived as a registry for future studies. As each CT scanner has unique performance capabilities, scan techniques were optimized and validated by the participating CT technologists, radiologists and institutional medical physicist before the study began. Study images were interpreted and archived on a Philips iSite Picture and Archiving and Communication (PACS) System. Images were viewed and interpreted in soft tissue, bone, lung and brain algorithms. The radiologists were also provided coronal and sagittal reformats for interpretation.

Following the scan, cases received standard forensic autopsies, including examination of the skull and brain and toxicologic evaluations. Potential cases to be included in the study were identified by the supervising radiologic technologist from the day's docket, a list of incoming cases and their circumstances. Any potential cases were flagged for follow-up to ensure they met cohort inclusion criteria once cause and manner of death were determined by the case pathologist. Cases were assigned NIJ study numbers, one for pathology/autopsy and a different one for radiology, with the linkage to OMI case numbers maintained by the supervising radiologic technologist.

UNM board-certified radiologists with the appropriate subspecialty training and experience interpreted all PMCT scans. A core team of four radiologists reviewed most cases. However, a subspecialty-trained pediatric radiologist interpreted cases in the pediatric subset and a neuroradiologist read the head and neck portions of the non-pediatric studies. For all cases, radiologists were provided with the same investigative and circumstantial information before

interpreting the PMCT scan that was available to the case forensic pathologist prior to autopsy. The project's radiologic technologist transferred this information, along with scene photographs, from the OMI database (a customized version of VertiQ CME software) to a secure server accessible by the radiologists. The radiologists were blinded to the autopsy findings prior to evaluating the PMCT scans, and pathologists were blinded to all PMCT scans.

Blunt force injuries

The radiologists completed a standard dictation for the PMCT scan and then determined a cause of death (disease or injury that initiates the fatal sequence of events) based on the investigative information and the PMCT findings. Their completed dictations were sent electronically to an AIS-certified coder, who entered both a text description and its associated AIS score for each injury recorded in the radiology report. The coder entered all scores and text descriptions into a Research Electronic Data Capture (REDCap) (49) database detailed below. AIS scores were assigned using the 2008 guidelines (50). The supervising radiologic technologist was responsible for assigning NIJ radiology numbers (to use instead of the OMI case number) as well as preparing and sending radiology reports to the AIS coder.

The autopsy pathologists described the autopsy findings and determined a cause of death using the circumstantial information and autopsy findings as per routine protocols. These findings were entered in the usual format into the OMI electronic medical examiner record, and the case was assigned a unique NIJ autopsy number, different from the NIJ radiology number for the same case. After redacting the OMI case number (to blind the AIS coder to any association with the radiology report for that same case), the OMI autopsy report was sent electronically to the AIS coder. The supervising radiologic technologist was responsible for redaction, preparation and submission of the autopsy reports to the AIS coder.

After all blunt force injury (BFI) radiology and autopsy reports had been coded and entered into REDCap, the data were exported and matched on original OMI case number (linkage maintained by the supervising radiologic technologist) and prepared in an Excel spreadsheet for review during consensus conferences. Vertical columns with autopsy and radiology findings (both in text and seven-digit AIS scores) for each decedent were found to be easiest for review. The completed cases were reviewed in a consensus conference by a study pathologist and a study radiologist, neither of whom worked on the original case, to determine if each injury was a match (M with the number of the match) between autopsy and PMCT. If not a match between autopsy and PMCT, and the finding was seen on autopsy and not on PMCT but should have been, it was coded as R1, false negative by PMCT. Injuries which were seen on PMCT but not on autopsy and should have been were assigned a code of A1, false negative by autopsy. A2 was assigned to findings seen at PMCT and missed by autopsy but were in an area not dissected at autopsy and R2 was used for findings seen at autopsy and missed by PMCT but were out of the CT imaging field or were beyond the resolution of a PMCT scan. A data set of total injuries (those seen only at autopsy + those seen only on PMCT + those seen on both autopsy and PMCT) was established through these consensus conferences. The combined team of radiologists and pathologists also reached consensus on the cause of death, determining if the cause of death was correctly determined by autopsy, PMCT or both.

We compared maximal AIS (MAIS) scores by calculating kappa statistics between autopsy and PMCT for each AIS region: head, face, chest, abdomen, extremities and external (34). Injury Severity Scores (the sum of squares of the highest AIS scores in three different body regions) between the radiology results and the forensic pathology results were categorized by percentage of cases where the PMCT scores were equal to the autopsy scores, greater than

autopsy scores, and less than autopsy scores (34). This process was preferable to comparing PMCT to autopsy as a reference standard because there were instances where standard autopsy did not identify injuries found on PMCT, such as gas emboli and pneumopericardium (8). To address whether PMCT should supplement autopsy we calculated the sensitivity of blinded autopsy discovered injuries against the total injuries (CT + autopsy) as the reference standard (34).

Firearm injuries

The supervising radiologic technologist prepared de-identified OMI investigative and circumstantial information for deaths due to gunshot wounds (GSWs), and assigned an NIJ GSW radiology cohort study number for use by the radiologists, different and non-sequential from the NIJ GSW autopsy cohort study number. In addition to this information, the radiologists were provided with a redacted diagram of the location of all wounds on the body surface, but were not told whether they represented entrance or exit wounds. External surface information such as soot and stippling were included on the diagram, as this would be information the pathologist would have access to from the external examination. The radiologists identified all wound tracks and organs disrupted or injured, as well as the trajectory of each wound in three axes (front-back, right-left, up-down). The radiologists dictated a radiology report with all their findings, which was then sent to the AIS coder. The coder entered all reported trajectories, purported entry and exit points and all additional injuries by both text description and AIS code where relevant into the Firearms REDCap database.

The autopsy case pathologists used a combination of standard x-ray and autopsy to identify the wound tracks and trajectories (the same three axes: front-back, right-left, up-down) and to recover projectiles. The case pathologists were blinded to the PMCT findings and

described the autopsy findings to be entered in the usual format into the OMI electronic medical record. OMI autopsy reports, with OMI case numbers redacted, were assigned a unique NIJ number and sent to the AIS coder for coding and entry into REDCap.

After all GSW radiology and autopsy reports had been coded and entered into REDCap, the data were exported and matched on original OMI case number (linkage maintained by the supervising radiologic technologist) and prepared in an Excel spreadsheet for review during a consensus conference. Vertical columns with autopsy and radiology findings for each decedent, as used previously in the BFI cohort, were found to be easiest for review. The completed cases were reviewed in a consensus conference by a study pathologist and a study radiologist (neither of whom worked on the original case) to determine which PMCT gunshot injuries were autopsy confirmed, which PMCT gunshot injuries were definitely not seen at autopsy, which injuries were seen at autopsy but not on PMCT, and which PMCT gunshot injuries were in a region not evaluated by autopsy. Trajectories and entry/exit wounds were compared for single GSW deaths. A data set of total gunshot injuries (those seen only at autopsy + those seen only on CT + those seen on both autopsy and CT) was created.

To address whether CT can supplant autopsy, we evaluated the blinded CT-discovered injuries against the blinded autopsy-discovered injuries. As with blunt force injuries, we compared severity scores between CT and autopsy results and calculated kappa values for reproducibility of MAIS regional scores and trajectory determination (34). Injury Severity Scores (the sum of squares of the highest AIS scores in three different body regions) between the radiology results and the forensic pathology results were categorized by percentage of cases where the PMCT scores were equal to the autopsy scores, greater than autopsy scores, and less than autopsy scores (34)

To address whether CT should supplement autopsy we calculated the sensitivity, specificity and positive and negative predictive values of the blinded autopsy discovered injuries against the total injuries (CT + autopsy) as the reference standard (34).

Childhood Traumatic Injuries

Childhood traumatic deaths were processed the same way as traumatic deaths in older decedents included in the Blunt Force Injuries cohort. The radiologists reviewed the PMCT scans and completed a radiology report with their findings, as well as a cause of death. Radiology reports on childhood traumatic death cases were assigned an NIJ Pediatric Cohort-Radiology number and sent to the AIS coder, who assigned AIS scores and brief text descriptions for all described injuries and entered the data into the REDCap Radiology database.

The autopsy case pathologists were blinded to PMCT findings and described the autopsy findings, including standard skeletal x-rays, and determined a cause of death using the circumstantial information, the autopsy and x-ray findings. These findings were entered in the usual format into the OMI electronic medical record, the autopsy report was assigned an NIJ Pediatric Cohort-Autopsy case number, the OMI case number redacted, and the report sent to the AIS coder for scoring and entry into the NIJ Autopsy REDCap database.

Following entry of the blinded autopsy and PMCT findings into the REDCap database, the autopsy and PMCT AIS-scored injuries were exported as an Excel spreadsheet and the cases matched on the original OMI case number, with the linkage to NIJ study numbers maintained by the supervising radiologic technologist. Autopsy and PMCT injuries, organized by the 6 AIS regions (head, face, chest, abdomen, extremities, external) were arrayed vertically, side-by-side for each decedent. These completed cases were reviewed by a study pathologist and a study radiologist (neither of whom was involved in the original autopsy or PMCT interpretation) to

determine which PMCT injuries were confirmed by autopsy (a match, coded by M with the number of the match for that decedent), which PMCT injuries were not seen at autopsy (coded A1), which injuries were seen at autopsy but not on PMCT (coded R1), which PMCT injuries were missed by autopsy but were in an area not dissected (A2) and which injuries were seen at autopsy and missed by PMCT but were out of the CT imaging field or were beyond the resolution of a PMCT scan. (R2). A data set of total injuries (those seen only at autopsy + those seen only on PMCT + those seen on both autopsy and PMCT) was established. The combined team of radiologists and pathologists also reached consensus on the cause of death, determining if the cause of death from the autopsy was correct, if the one from PMCT was correct, or if both were correct or incorrect.

As with blunt force injuries and gunshot wounds, we compared severity scores between PMCT and autopsy results and calculated kappa values for reproducibility of MAIS regional scores (34). Injury Severity Scores (the sum of squares of the highest AIS scores in three different body regions) between the radiology results and the pathology results were categorized by percentage of cases where the PMCT scores were equal to the autopsy scores, greater than autopsy scores, and less than autopsy scores (34).

Potential Drug Poisoning Deaths:

The radiologists completed dictations of the PMCT scans. Radiologists were provided with circumstantial evidence, scene photographs and external photos of the body taken at autopsy. The autopsy case pathologists were blinded to the PMCT findings and described the autopsy findings and determined a cause of death using the circumstantial information, the autopsy findings and the toxicologic findings. These findings were entered in the usual format into the OMI electronic medical record and a death certificate completed. The completed

autopsy and radiology reports (both with unique NIJ numbers) were sent to the AIS coder and her coded entries were entered into the NIJ Tox Cohort REDCap database, which had entries for disease and diagnostic findings, in addition to the usual AIS regions.

Because determination of the cause of death in potential poisoning deaths is complex and beyond the experience of radiologists we used a different approach in this cohort. A different study forensic pathologist was provided with the findings of the external examination portion of the autopsy but was blinded to the visceral findings. The study forensic pathologists were also provided with the investigative and circumstantial information, the PMCT findings (radiologist dictation) and the toxicologic findings. The study forensic pathologists then determined a cause of death that was entered into an Excel spreadsheet, along with the original cause of death from the death certificate.

The completed cases were reviewed by a team of one study pathologist (not involved with the original autopsy or as a study pathologist in determining the cause of death as above) and one study radiologist (not involved in the original evaluation of the PMCT) to determine which injuries or diseases seen by PMCT were autopsy confirmed, were definitely not autopsy confirmed, or were in a region not evaluated by autopsy, and which injuries and diseases were seen at autopsy but not at PMCT. A data set of total injuries and diseases (those seen only at autopsy + those seen only on PMCT + those seen on both autopsy at PMCT) was abstracted for the results included in this report.

To address whether PMCT can supplant autopsy we evaluated the investigation + external examination + PMCT discovered injuries and diseases + toxicologic evaluation against the investigation + PMCT-blinded autopsy discovered injuries and diseases + toxicologic evaluation for cause of death determinations and for injuries and diseases recognized. We

compared the MAIS and ISS scores determined by the attending pathologist to those assigned by blinded study forensic pathologists, and calculated kappa values for reproducibility (34). Presence/absence of injury by region was compared between CT and autopsy results (34).

REDCap Database

REDCap (Research Electronic Data Capture) is a metadata-driven software application and metadata-gathering workflow that was designed to support translational academic research (49). REDCap was developed to provide investigators with intuitive and reusable tools for collecting, storing and disseminating data. REDCap allows collaborative access to data across academic departments and institutions (49). This research asset is available for free to all UNM faculty members through the Clinical Translational Science Center as part of the Informatics Core function. The project-specific database was developed in conjunction with support from Informatics Core staff.

Data analysis

Data from the NIJ Autopsy and NIJ Radiology REDCap database were exported into Excel and prepared for review in consensus conferences by matching AIS-coded autopsy and PMCT reports on original OMI case numbers. After all injuries were assessed in consensus conferences, the data were abstracted into an Excel spreadsheet and imported into SAS (Statistical Analysis Software) version 9.2 for analysis. To determine when CT might be sufficient to supplant traditional autopsy, the autopsy alone cannot be used reliably as a "gold standard" necessitating the comparison of PMCT and autopsy by presence/absence of injury and disease by region, and overall ISS (34) We calculated kappa values for MAIS scores by region in order to determine agreement between the two modalities, adjusting for agreement seen by chance alone (51). A previous study found good agreement for AIS reproducibility between CT

and autopsy (34). The numbers of injuries found by region by both autopsy and CT are included in the Results sections, as are the kappa statistics calculated to compare MAIS scores by region and comparisons of overall ISS scores. Sensitivities were calculated using all matched findings as true positives, and findings coded as R1 or A1 as false negatives. Continuous variables were compared using either t-tests or Wilcoxon rank sum tests as appropriate for the sample size, and categorical variables were likewise assessed using either Chi square or Fisher exact tests based on sample size. P-values of 0.05 or less were considered statistically significant.

III. Results

1. Statement of Results

A. Blunt Force Injury Cohort: Preliminary power calculations estimated that 197 cases would be needed to achieve a power of 90%. The blunt force injury (BFI) study arm ran from June 5, 2011 through April 5, 2012 and resulted in 174 cases being enrolled, resulting in a lower but acceptable power of 88%. Seven of the decedents sustained severe thermal injuries as well as blunt force injuries, and will need to be assessed separately. The remaining 167 BFI decedents comprised 39.5% white non-Hispanic, 32.9% white Hispanic, 23.4% American Indian, and 2.4% African American (Table 1). Compared to New Mexico's general population (47), American Indians were over-represented in this cohort and white Hispanics under-represented. Males made up 75.4% of the BFI study section and had a mean age of 41.8 years, not significantly different from the 41 women included with a mean age of 41.2 years (Table 2). The majority (80.2%) of the deaths included were determined to be accidental, but 22 (13.2%) were homicides, six (3.6%) were suicides and 5 (3%) were undetermined in manner (Table 3). Almost half the included BFI deaths (82, 49.1%) were due to motor vehicle crashes, followed by assault (15%), pedestrians struck by vehicles (10.2%), motorcycle crashes (7.8%) and falls from height (4.2%) (Table 4).

Overall there was good agreement between the cause of death assigned by autopsy and the one assigned by radiologists using the PMCT scan (Table 5), with both assessed as correct and matching in 85% of blunt force deaths. In 10.2% of cases, the PMCT cause of death was determined to be incorrect and the autopsy cause of death correct, whereas in six (3.6%) of blunt force trauma deaths, the PMCT cause of death was determined to be the correct one, and in two deaths neither the autopsy nor PMCT cause of death was determined to be correct. In these two

cases, one a homicidal assault and the other a motor vehicle crash fatality, neither cause of death was assessed to be complete as written, with each physician mentioning only a partial contribution to the cause of death or not specifying the location adequately, such as "multiple injuries". Looking at mean numbers of injuries detected by region (Table 6), more injuries were detected by PMCT for each of the six AIS regions (head, face, chest, abdomen, extremities, and external) except the external region. PMCT resulted in a significantly higher mean number of injuries detected per region than autopsy in the head, chest, abdomen and extremities ($p<0.0001$ for all four regions). The difference in mean number of injuries for the face was not significant ($p=0.14$), and autopsy detected a significantly higher mean number of injuries in the external region ($p<0.0001$).

Comparing numbers of injuries detected by autopsy to the number of injuries detected by PMCT (Figure 1, Table 7), significantly more injuries were detected by PMCT than autopsy ($p<0.0001$). During consensus conference, each injury found was determined to be either a match with a corresponding injury found on the other technique, a "1" (missed but should have been seen) or a "2", missed but would not have expected to have been seen (Table 8). In the BFI cohort, 46.6% of findings were coded as "matches" (Table 7). The head had the highest percentage of matched findings (54.1%), followed by the chest (48.7%) and face (46.8%). The abdomen had the lowest percentage of findings coded as a match. Looking at Table 8, where unique findings were used as the denominator (total findings by region minus one set of the duplicate matched findings), 20.4% of unique injuries seen on autopsy were not seen on PMCT, with the highest percentages of R1 (should have been seen on PMCT) injuries noted in the external region (38.7%) and the head (22.9%), with the fewest R1s noted in the extremities (7.3%) and face (9.5%).Only 6.2% of the unique injuries seen were determined to be in an area

outside the imaging capability of the CT scanner, with the highest percentage (26.4%) being in the external region. Similarly, 21.2% of unique injuries were seen on PMCT but not on autopsy, with the highest percentages of missed injuries being in the abdomen (31.3%) and head (24%). Just over 19% of unique injuries were determined to be in areas not routinely dissected at autopsy, with most of these being in the extremities (36.7%) and abdomen including spine (28.6%). Calculating sensitivity for PMCT in blunt force trauma deaths resulted in a value of 74.1%, and for autopsy, 73.4%.

The three highest AIS scores by region are squared and summed to provide the Injury Severity Score (ISS). When comparing the ISS assigned to a decedent by autopsy to the one arrived at by PMCT, the mean ISS score for autopsy (38.6) was higher than that for PMCT (35.9) but the difference was not statistically significant (p=0.08). In 35 cases (21%), autopsy- and PMCT-assigned ISS scores were identical (Table 9, Figure 2), while in 41.3% of deaths the autopsy-assigned ISS was more severe than the PMCT-assigned ISS. In 20 decedents (12%), both the autopsy and PMCT resulted in the maximum ISS of 75 (non-survivable). In 79 BFI decedents (47.3%), the ISS assigned by autopsy results was 10 or more points different (either greater or lesser) than the ISS score assigned by PMCT. Autopsy was significantly more likely to assign the highest ISS score than PMCT (p=0.02). Distributions of other, lower ISS scores between autopsy and PMCT were quite similar (Table 10, Figure 3).

Comparing agreement between autopsy and PMCT using kappa statistics (which correct for agreement seen by chance alone) in the assignment of the maximal (most severe) AIS score by region, moderate agreement is seen when assessing severity in the chest and extremities (Table 11). The head, face and abdominal regions all demonstrated fair agreement using the scale

developed by Landis and Koch (51), while the external region only had slight agreement between autopsy and PMCT in the assignment of the MAIS.

When evaluating which findings were seen on PMCT but most commonly missed on autopsy (Table 12), cerebral intraventricular hemorrhage was the finding most commonly coded as A1 in the BFI cohort, meaning that it should have been seen on autopsy but was not (ie, false negative). This was followed in frequency for A1 coding by pulmonary contusions, subarchnoid hemorrhage, subgaleal hematomas, subdural hematoma and mediastinal hematomas. The top five spots for the findings most frequently coded as A2 (would not have expected to have seen these at autopsy) included transverse process fractures of lumbar vertebrae, pneumothoraces, transverse process fractures of thoracic vertebrae, and pneumocephalus. A similar breakdown of findings missed on PMCT (Table 13) revealed external lacerations as the injury most likely to be missed on PMCT which should have been detected, followed by external contusions, subarchnoid hemorrhage, hemothorax, liver lacerations and lung lacerations. Abrasions were the most common R2 finding, followed by pleural lacerations, scleral hemorrhage, external lacerations and pericardial lacerations. Comparing how many of the missed findings that should have been seen which were of moderate to extreme severity (AIS severity scores of 4, 5, 6) (Figure 4), there was no significant difference between autopsy and PMCT (13.4% versus 16%, $p=0.16$) (Figure 4). However, only three of the missed A1 findings were scored as six (most severe), compared to 22 of the missed R1 findings, a significant difference ($p=0.0001$).

B. Firearms Fatalities Cohort

From April 6, 2012 through January 15, 2013, 205 firearm fatalities were enrolled in the study. Two of the deaths involved extensive thermal damage from fire in addition to injuries from gunshot wounds, and were excluded from this analysis due to the difficulty in ascribing injuries to the appropriate cause. The remaining 203 decedents were 87.7% male, and most (86.7%) died from a single gunshot wound (Table 14). The majority of deaths (70%) were suicides, with 27.6% homicides and five GSW deaths undetermined in manner. White non-Hispanics were over-represented in this study section when compared to New Mexico's general population (54.7% versus 39.4%) (47). There was no statistically significant difference in mean age by gender, but decedents dying from multiple GSWS were significantly younger than decedents who died from a single GSW ($p=0.01$). Handguns were the most commonly noted firearms used in single GSW deaths (65.9%), followed by shotguns and rifles (Table 15). In over 44% of multiple GSW deaths, the weapon used was unknown.

In 99.5% of firearm fatalities studies, the cause of death determined by autopsy matched the cause of death determined by the radiologists working from the PMCT scans (Table 16). There was a moderately strong positive correlation in the ISS assigned to GSW deaths by PMCT and autopsy ($r=0.59$). In 32.5% of cases, the ISS assigned by autopsy was equal to the one assigned by PMCT (Table 17). In 73/203 (36%) deaths, the ISS scores from each technique were within five points of one another (53% of cases where the ISS scores were not an exact match). The agreement between autopsy and PMCT MAIS scores by region (Table 18) ranged from slight for the external region to substantial for the head and chest.

Findings coded as "misses" (either 1 or 2) were evaluated to determine which injuries were most often missed by each technique (Tables 19 and 20). Intraventricular hemorrhage was the finding most often missed by autopsy (Table 19) which, in the opinion of the reviewing physicians, should have been detected, followed by subdural hematomas, facial fractures, mediastinal hematomas, and rib fractures. Pneumocephalus was the finding most often coded as "A2", missed but would not be expected to be seen at autopsy. Other frequently missed "A2" findings included pneumothorax, maxillary fractures, orbital fractures and fractures of vertebral processes. Findings most commonly missed on PMCT which should have been seen (R1, Table 20) include multiple contusions, subgaleal hemorrhages, external lacerations, hemothorax and brain contusions. Injuries most commonly coded as R2 in the GSW cohort included external abrasions, periorbital ecchymoses and perforations, and pericardial perforations (Table 20). Comparing severity of missed findings between autopsy and PMCT (Figure 5), significantly more missed autopsy findings rated a "1" were of moderate to severe AIS score (4, 5, 6) than missed PMCT findings rated a 1 ($p=0.03$). Seventeen A1 findings were scored with a six (most severe, non-survivable) as were 25 R1 findings, though this difference was not significant. Assessing how often PMCT detected the same number of total GSWs as autopsy (Figure 6), accuracy was 100% with up to three GSWs. This dropped to 50% for decedents with four or five separate GSWs, and then rose to 66% for six wounds. Accuracy dropped precipitously for seven and eight wounds.

Focusing on the 176 deaths due to a single gunshot wound, males were over-represented at 89%, and white non-Hispanics were over-represented at 60% of the study cohort (Table 21). In these deaths, PMCT described a significantly higher mean number of injuries per decedent than autopsy ($p<0.0001$) (Table 22). Regarding severity as measured by ISS (Table 23) however,

revealed no significant difference in mean ISS assigned (p=0.38). There was a moderately strong positive correlation between ISS assigned by autopsy and those assigned by PMCT (r=0.59). There was a wide range in agreement between MAIS scores as measured by kappa statistics for single GSW deaths, ranging from poor for the external region to substantial for the head and chest (Table 24).

Both PMCT and autopsy correctly identified entry wounds in 91% of single GSW cases (Table 25). There were 13 single GSW cases (7.4%) where the exit wound determination did not match between autopsy and PMCT, with 12 of those found to be correct by autopsy and one correct by PMCT (Table 26). In another 25 deaths, there was no discrete exit wound, rather a large anatomical area such as the top of the head was missing, making it non-applicable to identify a single exit wound.

Radiologists and pathologists were asked to determine the bullet's trajectory on three axes, up/down, front/back and left/right. For cases with a single gunshot wound, the left/right trajectory was most frequently correctly identified by both techniques, with 84.7% of the cases correctly identified as to left/right trajectory (Table 27). Up/down trajectory was correctly identified in 79% of the cases, and front/back in 72.2% of the cases studied. In almost all cases where the trajectories did not match, the autopsy determination was ruled to be correct, except for one up/down determination and one front/back determination. There were two cases where a single bullet exited and re-entered the body (Table 28), and PMCT correctly identified the up/down and left/right trajectory in both cases, and the correct entry and exit in one case.

Since gunshot wounds often traverse more than one AIS region, injuries were assessed by gunshot wound rather than AIS region, currently precluding the assessment of injury counts by

AIS region for the this cohort. PMCT identified more injuries than autopsy (Table 29). Of all findings (autopsy + PMCT), 64.9% (2,108) were coded as matches, either 1:1 or in some cases more than one finding matched to a single injury from the other technique. To calculate the number of unique findings, we subtracted one set of the 1:1 matches from the total findings (3,246-881) to remove duplicate findings. Fifteen percent of these 2,365 unique GSW findings identified were not seen on PMCT but should have been, and 7.1% were below the imaging resolution of PMCT. Similarly, 16.8% of unique injuries were not seen on autopsy but should have been, in the opinion of the consensus conference reviewers, and 9% were in areas of the body not routinely dissected at autopsy. While the difference in A1 and R1 findings was not significant ($p=0.13$), the difference in A2 and R2 findings was ($p=0.02$). Calculating sensitivity for PMCT in single GSWs resulted in a value of 82.1%, and for autopsy of 84.2%.

Assessing wounds in deaths with more than one gunshot wound, there were 21 male (77.8%) and six female decedents with multiple gunshot wounds, the majority of whom were white Hispanic (70.4%) (Table 30). Autopsy identified slightly more GSWs than PMCT (Table 31), but the difference was not significant ($p=0.15$). Likewise the assigned ISS scores were very similar between autopsy and PMCT for multiple GSW victims (Table 32), and had a moderately strong positive correlation ($r=0.54$). PMCT detected a significantly higher mean number of injuries in multiple GSWs than autopsy ($p=0.02$) (Table 33). Totaling the injuries detected by autopsy with those seen on PMCT, there were 903 total findings, with 574 (63.6%) coded as matches between techniques. From 668 unique findings in multiple GSW cases, PMCT missed 16.9% that should have been seen (R1, Table 34). Seven percent of these unique finding were missed but would not have been expected to be seen (R2). Autopsy missed 18.4% of unique findings that should have been detected (A1), and missed 6.9 that would not be expected to be

seen on autopsy (A2). The differences in findings coded A1 and those coded R1, as well as between A2s and R2s, were not significant (p=0.47 and 0.91, respectively). Sensitivity for PMCT in multiple GSW deaths was 83.6%, and for autopsy was 82.4%.

Agreement in assignment of MAIS by region between autopsy and PMCT in multiple GSWs varied from slight in the external region to substantial in the chest and abdomen (Table 35). Entry and exit wounds, as well as trajectory, as determined from PMCT were compared to autopsy results for multiple GSWs (Table 36). In 68.2% of evaluated cases, the entry wound as determined by PMCT matched that determined by autopsy, as did 63.5% of exit wounds. Determining trajectory for multiple GSWs appeared to be more difficult, as only 43.9% of PMCT-determined up/down trajectories were correct when compared to autopsy, as were 49.5% of left/right and 57.9% of front/back trajectories.

C. Pediatric Trauma Deaths

The pediatric traumatic death cohort enrolled cases from June 5, 2011 through December 31, 2013. We originally had 76 cases, but 11 were unblinded by attending pathologists. Two of the cases had sustained severe thermal damage, making it impossible to assess if injuries were due to thermal damage or traumatic injury, leaving a current study cohort of 63 cases (Table 37). The majority (63.5%) of decedents were male, and most deaths (81%) were determined to be accidental in manner, with another 19% ruled homicides. American Indians were over-represented when compared to the general New Mexico population (27% versus 10%). The highest percentage of cases by age group for both males and females was in the under one year category (Figure 7).

The most common mechanisms of death in the pediatric trauma death cohort included co-sleeping and suffocation, which accounted for 33.4% of the deaths, followed by assault (14.3%) and motor vehicle crashes (12.7%) (Table 38). When comparing cause of death assigned by autopsy to cause of death assigned by PMCT, both were deemed correct by consensus review for 81% of the cases (Table 39). Autopsy was felt to be the correct cause of death in 17.5% of cases where PMCT cause of death was incorrect, though in one death (a premature baby whose mother had been in a car accident), reviewers determined the PMCT-assigned cause of death was the correct one, and the autopsy cause of death was incorrect.

Interestingly, autopsy detected more injuries in this pediatric cohort than PMCT (Table 40), in contrast to the blunt force and firearm cohorts, where PMCT identified higher numbers of injuries. In pediatric trauma deaths, 271 (41.7%) findings were coded as a “match”, with 379 (58.3%) findings deemed to be a miss (Table 41). Thirty-three percent of findings were not seen

on PMCT and should have been (R1), and 11.8% were deemed to be outside the imaging resolution of the CT scanner. Regarding autopsy, 21.1% of unique findings were not seen on autopsy but should have been, and 7.2% were in areas that would not be routinely dissected during autopsy. The percentage of R1 misses was significantly ($p<0.0001$) higher than the percentage of A1 misses, as was the percentage of R2 misses when compared to A2 misses ($p=0.01$). The sensitivity of PMCT in pediatric trauma deaths was 61.2%, and for autopsy was 71.3%. The overall ISS was within one point between autopsy and PMCT in 50.8% of pediatric trauma deaths, and autopsy resulted in a more severe ISS than PMCT in 34.9% of cases (Table 42), and agreement between autopsy and PMCT in assigning MAIS ranged from fair (head, abdomen, external) to moderate (face, chest) to substantial (extremities) (Table 43).

When evaluating what types of injuries were most frequently missed on autopsy (Table 44), cerebral intraventricular hemorrhage was the most common finding coded as "A1", meaning it was missed but in the opinion of the consensus reviewers it should have been seen. This was followed by pulmonary contusions, compression fractures of thoracic vertebrae, intraparenchymal hemorrhage and subarachnoid hemorrhage. Pneumothorax, followed by pneumocephalus, pneumopericardium and pneumomediastinum were the PMCT findings most commonly determined to be "A2", in that they would not normally be seen on autopsy or were in a part of the body that is not normally dissected at autopsy. Conducting a similar analysis of PMCT findings (Table 45), contusions were the finding most frequently coded "R1," with the implication that the radiologist should have seen the finding but did not. Contusions were followed by subdural and subarachnoid hemorrhages, cerebral edema and lung contusions. Abrasions were the most common "R2" finding (would not expect to have seen on PMCT), followed by diaphragmatic contusions, pleural lacerations and cervical nerve root hemorrhages.

The majority of A1 and R1 “missed” findings (88% and 86%) were of mild to moderate severity, with AIS severity scores of 1-3 (Figure 8). Six (3.5%) of the findings missed on PMCT were of the most lethal severity (6) as was one of the autopsy missed findings (0.9%). None of the A2 or R2 findings were rated a 6 on severity, though six R2 misses were a five in severity and three A2s were a five in severity. None of these differences were statistically significant.

D. Potential Drug Poisoning Deaths

Potential drug poisoning deaths were enrolled from January 16, 2013 through August 27, 2013, with 460 cases included. Three cases were excluded because investigative information was received by the autopsy pathologist after the cases had been initially included in the cohort and the information was not provided to the study pathologist, leaving a cohort of 457 deaths. Autopsy reports and PMCT reports were completed for all cases, as was a reviewing pathologist's cause of death statement (using PMCT and circumstantial information but not visceral results) and the results paired in Excel spreadsheets for review in consensus conference. Consensus conferences to review these cases and determine matches and misses began October 2014, and were completed in April 2015.

The drug poisoning cohort included 307 males (67.2%) and 157 females (32.8%), ranging in age from 15 years to 90 years (Table 46). The female decedents included were older than male decedents, but the difference was not significant (p=0.06). Other than an over-representation of white non-Hispanic decedents, the distribution of race/ethnicity was very similar to that of the New Mexico general population. Accident was the most common manner of death (51.2%), followed by natural (32.4%) and suicide (10.1%). As is commonly the case with New Mexico drug overdose deaths, males between the ages of 40 and 69 were the most heavily impacted age group (Figure 9).

More injuries and disease processes were recorded from the original autopsy than in the PMCT report used in the cause of death review (Table 47). Removing non-anatomic and non-relevant findings (x-codes and primary diagnoses), 7,121 findings remained, of which 2,734 were coded as matches (38.4%) and 5,349 (73.6%) as misses. After subtracting duplicates from

matched cases and findings ruled to be non-relevant or entered only as markers of primary diagnoses, 6,182 unique findings remained. Significantly more findings were ruled R1 (missed on PMCT and should have been seen) than were ruled A1 (missed on autopsy and should have been detected) (23.2% versus 15.3%, $p<0.0001$). Similarly, significantly more PMCT findings were coded as R2 (would not expect to have seen) than A2 (30.7% versus 15.4%, $p<0.0001$). Sensitivity of PMCT in drug poisoning deaths was 65.5%, and for autopsy it was 74.3%. The agreement between the maximal AIS scores assigned by region for autopsy and PMCT ranged only from poor (face, extremities) to fair (head), though in two of the regions there were very few injuries in the regions evaluated (Table 48).

In this cohort, autopsy detected significantly ($p<0.0001$) more mean injuries/disease processes per individual than PMCT (Table 49). Injury severity scores were comparable between autopsy and PMCT (Table 49, Figure 10), with both techniques assigning the same ISS (within one point) in 88% of all drug poisoning decedents.

Focusing on the cause of death (COD) statements generated by the original autopsy pathologist, and the one generated by the reviewing pathologist using PMCT findings, the first line of Part 1 of the death certificate was ruled a match and correct in both cases in 77.9% of drug poisoning deaths (Table 50). For the 101 cases where the two COD statements did not match, the autopsy COD was felt to be correct in 98 (97%) of the deaths, the reviewing pathologist's COD was judged to be correct in 2 of the cases, and neither one correct in one case. For the remaining lines (2-4) of Part 1 of the death certificate, all non-matched COD statements were ruled to be correct in the autopsy section. Similarly in Part 2, Line 1 was correct and matched in the majority of deaths reviewed with a Part 2 (122/169, 72.2%) and most mis-matched cases were assessed to be correct on autopsy. In three instances the reviewing

pathologist, using only PMCT, was felt to be correct, and in two deaths the consensus committee determined that neither COD was correct.

Comparing cause of death evaluations in decedents under the age of 40 (113 decedents) to those for decedents ages 40 and older (344 decedents) (Table 51), the first line of Part 1 of the death certificate was significantly more likely to match between the original autopsy and the reviewing pathologist in people under the age of 40 than those 40 and over (p=0.019). The first line of Part 2 was more similar between the two age cohorts, with no significant difference in percent matched and correct (63% and 74%, p=0.24). Autopsy was typically the correct source of the cause of death, in all mismatched cause of death statements in people under 50 and all but six of the mismatched lines in the over 40 group.

Assessing the findings most frequently missed on autopsy and PMCT (Table 52), we found that autopsy most frequently missed calcifications, fractures, nephrolithiasis, aspiration and diverticulosis, when in the opinion of the consensus reviewers those findings should have been identified on autopsy. The findings most commonly ruled "A2" included vascular calcifications of the carotid bifurcations, degenerative changes, fractures, and osteoarthritis. The most commonly missed findings on PMCT (Table 53) included external contusions, cardiomegaly, obesity, and pulmonary edema, which should have been detected and noted on the PMCT report. The most commonly reported R2 finding was "substance present on toxicology", followed by external abrasions, atherosclerotic stenosis and hepatitis.

2. Tables

A. Blunt Force Injuries (n=167 decedents)

Table 1: Demographics of BFI cohort

Race	Number of decedents	Percent in study cohort	Percent in NM population
White non-Hispanic	66	39.5	39.4
White Hispanic	55	32.9	47.3
American Indian	39	23.4	10.4
African American	4	2.4	2.5
Unknown	3	1.8	--

Table 2: Mean age in years by gender in BFI cohort

Sex	Number	Mean	St. dev.	Minimum	Maximum	Median
Female	41	41.2	17.6	16.0	80	43
Male	126	41.8	16.8	8.0	83	43
Overall	167	41.6	16.9	8	83	43

No statistically significant difference in mean age by gender (p=0.86)

Table 3: Manner of death in BFI cohort

Manner	Frequency	Percent
Accident	134	80.24
Homicide	22	13.17
Suicide	6	3.59
Undetermined	5	2.99

Table 4: Mechanism of death in BFI cohort

Mechanism	Number of deaths	Percent
Motor vehicle crash	82	49.1
Assault	25	15
Pedestrian	17	10.2
Motorcycle	13	7.8
Fall from height	7	4.2
Fall from standing height	5	3
Unknown mechanism	5	3
Other*	13	7.8

*Crushed, airplane crash, skiing

Table 5: Comparison of cause of death assigned by autopsy and PMCT in BFI

Cause of death	Frequency	Percent
Both correct	142	85
Autopsy correct	17	10.2
PMCT correct	6	3.6
Both incorrect	2	1.2

Table 6: Mean number of BFI findings detected by autopsy and PMCT by region

AIS Region	Mean # findings, autopsy	Mean # findings, PMCT	P value
Head	3.1	3.9	<0.0001
Face	0.53	0.69	0.14
Chest	2.8	4.35	<0.0001
Abdomen	0.99	2.36	<0.0001
Extremities	1.33	3.2	<0.0001
External	2.93	1.17	<0.0001
Overall	11.6	15.7	<0.0001

Figure 1: Number of BFI findings detected by autopsy and PMCT by AIS region

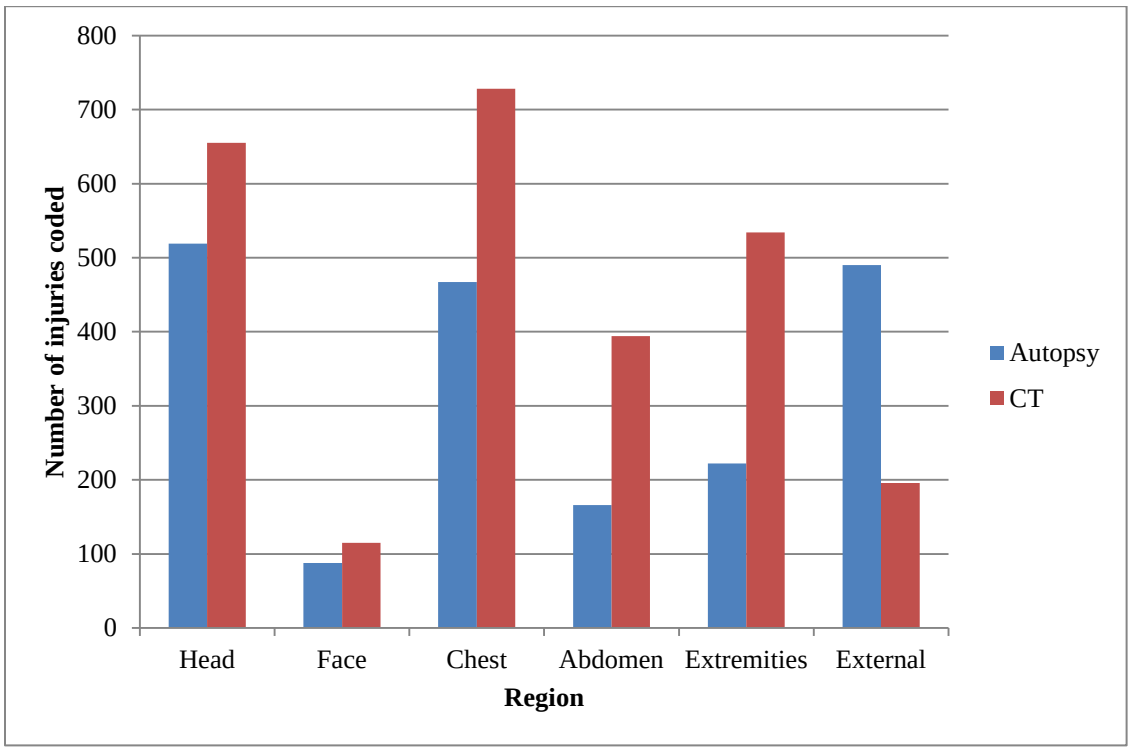


Table 7: Injury counts by AIS region for BFI cohort, autopsy and PMCT

AIS Region	Autopsy # of injuries	PMCT # of injuries	Total injuries	# of 1:1 matches	Multiple Matches	% of findings coded as M	Missed findings
Head	519	655	1174	261	113	54.1	539
Face	88	115	203	34	27	46.8	108
Chest	467	728	1195	268	46	48.7	613
Abdomen	166	394	560	71	29	30.5	389
Extremities	222	534	756	178	47	53.3	353
External	490	196	686	110	26	35.9	440
Total	**1952**	**2622**	**4574**	**922**	**288**	**46.6**	**2442**

Table 8: Missed injury counts for PMCT and autopsy, BFI cohort

AIS Region	Unique findings*	R1 count	R1 %	R2 count	R2 %	A1 count	A1 %	A2 count	A2 %
Head	913	209	22.9	22	2.4	219	24.0	89	9.7
Face	169	16	9.5	19	11.2	38	22.5	35	20.7
Chest	927	167	18.0	24	2.6	205	22.1	217	23.4
Abdomen	489	88	18.0	8	1.6	153	31.3	140	28.6
Extremities	578	42	7.3	0	0.0	99	17.1	212	36.7
External	576	223	38.7	152	26.4	59	10.2	6	1.0
Total	**3652**	**745**	**20.4**	**225**	**6.2**	**773**	**21.2**	**699**	**19.1**

*Total findings less one set of duplicate matched findings (1,174-261=913 for the head)

R1=Not seen on CT but should have been

R2= Not seen on CT but below/outside imaging resolution

A1=Not seen on autopsy but should have been

A2=Not seen on autopsy but in area not routinely dissected

Table 9: Injury Severity Score as assigned by CT and autopsy, BFI cohort

ISS	Number	% of total
PMCT more severe than autopsy	63	37.7
PMCT=Autopsy	35	21.0
Autopsy more severe than PMCT	69	41.3

Figure 2: Comparison of Injury Severity Score (ISS) between autopsy and PMCT, BFI cohort

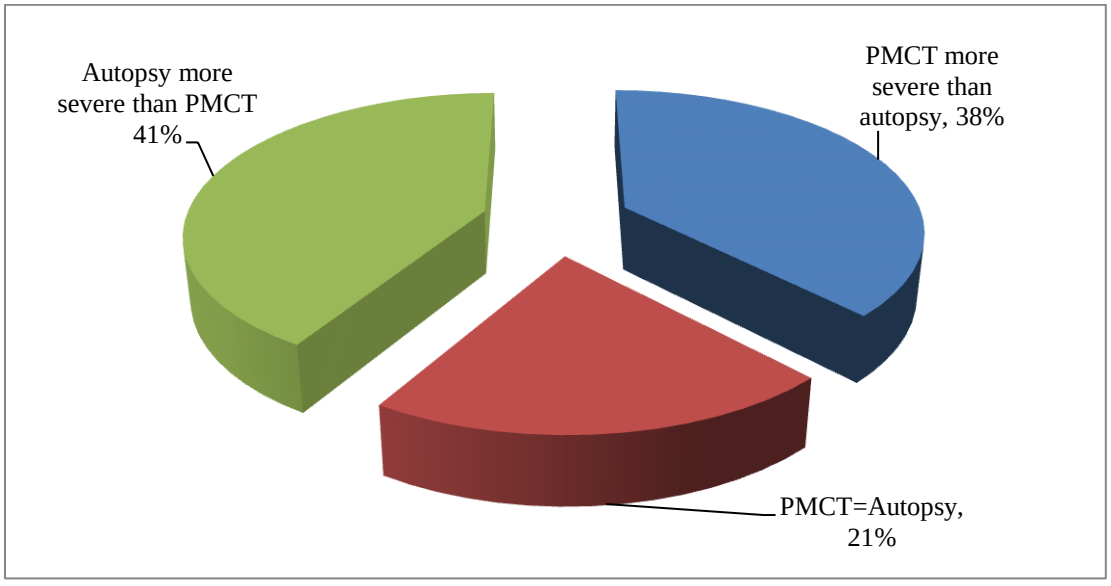


Table 10: Distribution of ISS scores by autopsy and PMCT, BFI cohort

ISS assigned	Autopsy		PMCT	
	Number	% of total	Number	% of total
1-10	14	8.4	16	9.6
11-25	37	22.2	41	24.6
26-50	70	41.9	76	45.5
51-74	5	3.0	10	6.0
75	42	25.2	24	14.4

Figure 3: Distribution of ISS assigned by autopsy and PMCT for BFI decedents

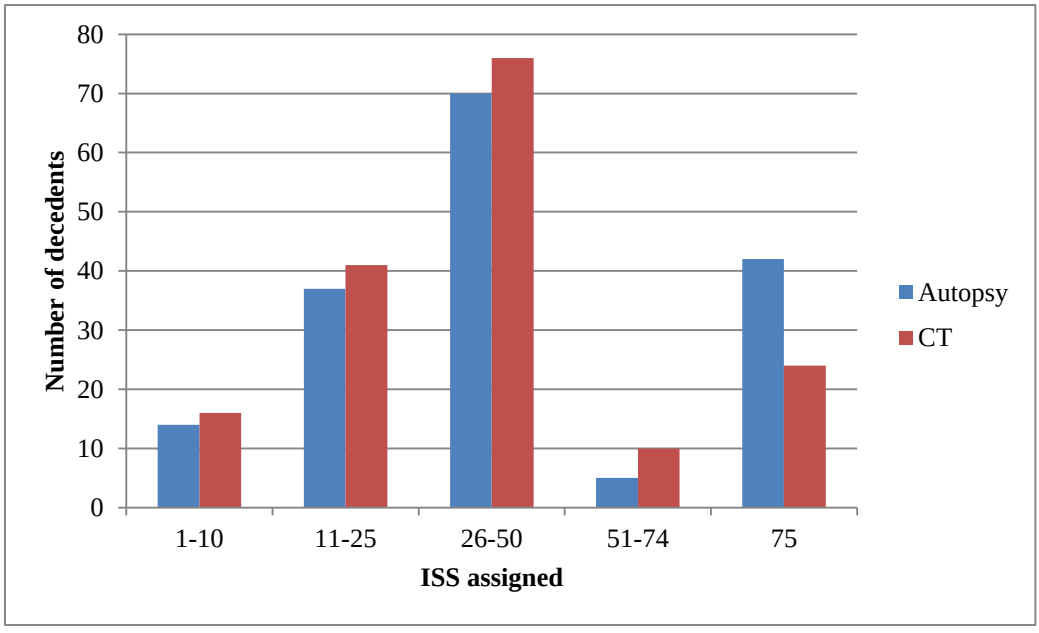


Table 11: Kappa statistics for BFI cohort by AIS region for maximal AIS score

Region	Kappa	Level of agreement
Head	0.33	Fair
Face	0.3	Fair
Chest	0.47	Moderate
Abdomen	0.36	Fair
Extremities	0.44	Moderate
External	0.12	Slight

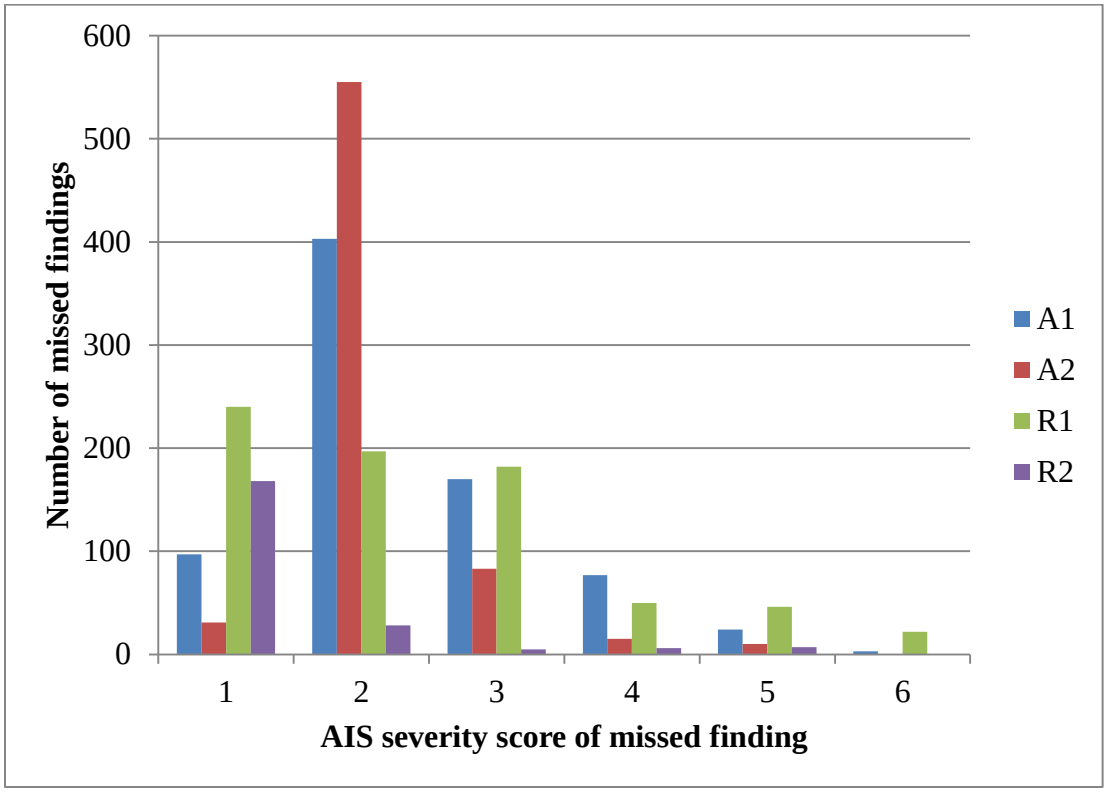
Table 12: BFI findings most commonly missed on autopsy by frequency

Findings coded as A1 (should have been seen)	Number	Findings coded as A2 (would not expect to have seen)	Number
Intraventricular hemorrhage	59	Transverse process fx lumbar vertebrae	115
Pulmonary contusions	46	L pneumothorax	54
Subarchnoid hemorrhage	33	R pneumothorax	54
Subgaleal hematoma	28	Transverse process fx thoracic vertebrae	54
Subdural hematoma	27	Pneumocephalus	53
Mediastinal hematoma	26	Scapula fracture	37
Sternal fracture	20	Spinous process fx thoracic vertebrae	37
Mesenteric hematoma	18	Acetabulum fracture	27
Splenic hematoma	15	Metatarsal fracture	15
Hemothorax	13	Spinous process fx cervical vertebrae	11
Cerebral edema	12	Maxillary fracture	8
Pulmonary lacerations	12	Metacarpal fracture	8

Table 13: BFI findings most commonly missed on PMCT by frequency

Findings coded as R1 (should have seen)	Number	Findings coded as R2 (would not expect to have seen)	Number
Lacerations, external	111	Multiple abrasions	135
Contusions, external	80	Pleural lacerations	10
Subdural hematoma	40	Scleral hemorrhage	9
Hemothorax	39	Lacerations, external	6
Liver lacerations	30	Pericardial laceration	4
Lung lacerations	19	Subconjunctival hemorrhage	4
Subarachnoid hemorrhage	18	Hypoxic ischemic changes	3
Lung contusions	18	Diffuse axonal injury	3
Atlanto-occipital dislocation	16	Liver lacerations	2
Sternum fracture	15	Basilar artery laceration	2

Figure 4: Distribution of severity scores for missed findings in the BFI cohort



B. Firearms Fatalities Cohort (n=203)

Table 14: Demographics of firearm fatalities cohort (n=203)

Characteristic	Number	Percentage
Number of GSWs		
Single	176	86.7
Multiple	27	13.3
Gender		
Male	178	87.7
Female	25	12.3
Manner of death		
Homicide	56	27.6
Suicide	142	70
Undetermined	5	2.5
Race/ethnicity		
White non-Hispanic	111	54.7
White Hispanic	75	37
American Indian	9	4.4
African American	5	2.5
Asian/Pacific Islander	2	1
Unknown	1	0.5
Mean age in years		
Males	44.9	
Females	44.2	
Overall	44.8	
Single GSW	46.1	
Multiple GSW*	36.4	

*Significant difference in means (p=0.01)

Table 15: Types of firearms used in firearm fatalities

Type of firearm	Single GSWs (n=176)		Multiple GSWs (n=27)	
	Number	Percent	Number	Percent
Handgun	116	65.9	12	44.4
Rifle	18	10.2	2	7.4
Shotgun	25	14.2	1	3.7
Unknown	17	9.7	12	44.4

Table 16: Cause of death comparison for firearm fatalities

Cause of death, all GSW deaths (n=203)	Number	Percent
Autopsy & PMCT, matched, both correct	201	99.5
Autopsy Correct, PMCT incorrect	2*	0.5

*One multiple GSW case, one decomposed decedent

Table 17: Firearm fatalities Injury Severity Scores assigned by autopsy and PMCT, compared

Comparing Injury Severity Scores, all GSW deaths	Number	Percent of total
Autopsy ISS=PMCT ISS	66	32.5
Autopsy ISS>PMCT ISS	68	34
Autopsy ISS< PMCT ISS	69	34
Total	203	100

Table 18: Kappa statistics for MAIS scores assigned by autopsy and PMCT, all gunshot wound decedents

MAIS kappas by AIS region, all GSW deaths	Kappa Statistic	Level of agreement
Head	0.74	Substantial
Face	0.32	Fair
Chest	0.71	Substantial
Abdomen	0.59	Moderate
Extremities	0.56	Moderate
External	0.03	Slight

Table 19: Findings most commonly missed by autopsy in firearm fatalities cohort

Findings coded as A1	Number	Findings coded as A2	Number
Intraventricular hemorrhage	102	Pneumocephalus	122
Subdural hematoma	37	Pneumothorax	48
Facial fractures	28	Maxillary fracture	18
Mediastinal hematoma	27	Vertebral transverse process fractures	13
Rib fractures	18	Orbital fractures	9
Cerebellar lacerations and contusions	17	Vertebral spinous process fracture	5
Skull fractures	14	Pneumomediastinum	2
Pulmonary lacerations	13	Pneumopericardium	2
Splenic laceration/hematoma	12	Intraventricular hemorrhage	2
Pulmonary contusions	11	Mandibular fracture	2

Table 20: Findings most commonly missed by PMCT in firearm fatalities cohort

Findings coded as R1	Number	Findings coded as R2	Number
Multiple contusions, external	60	Abrasions, external	74
Subscapular and subgaleal hemorrhages	52	Periorbital ecchymoses	44
Lacerations, external	32	Pericardial perforation	22
Hemothorax	25	Perforation pericardium	11
Brain contusions	21	Periorbital contusions	11
Perforation tongue	18	Contusions, external	6
Skull fractures	15	Laceration, external	6
Subarchnoid hemorrhage	10	Brain contusions	6
Hyoid fracture	9	Cardiac valve injury	4
Subdural hematoma	9	Incisions	3

Figure 5: Distribution of AIS severity scores for missed findings in the firearm fatalities cohort

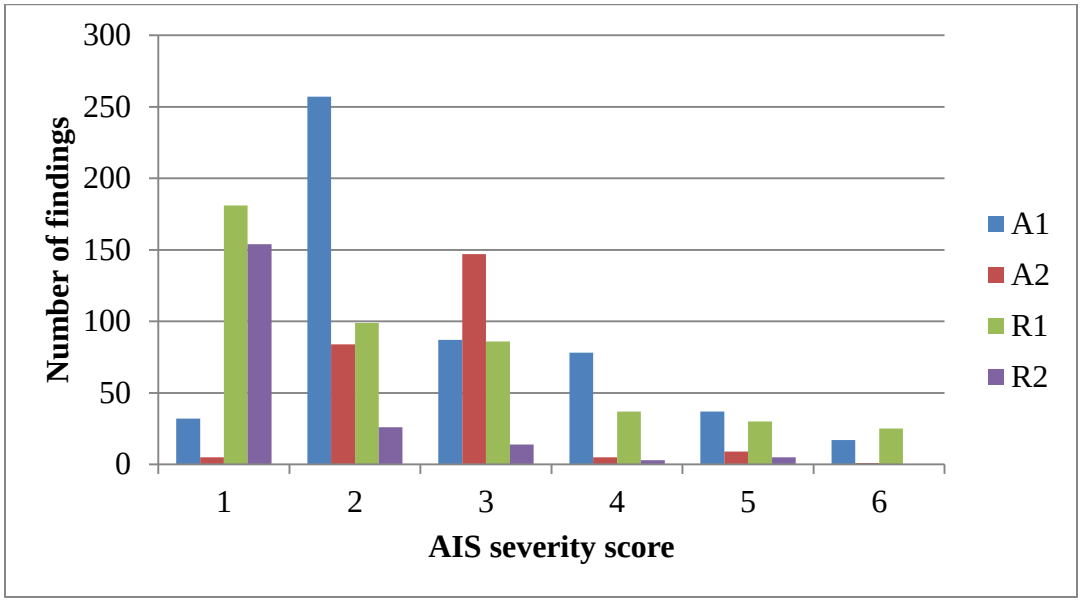


Figure 6: Accuracy of radiology gunshot wound count

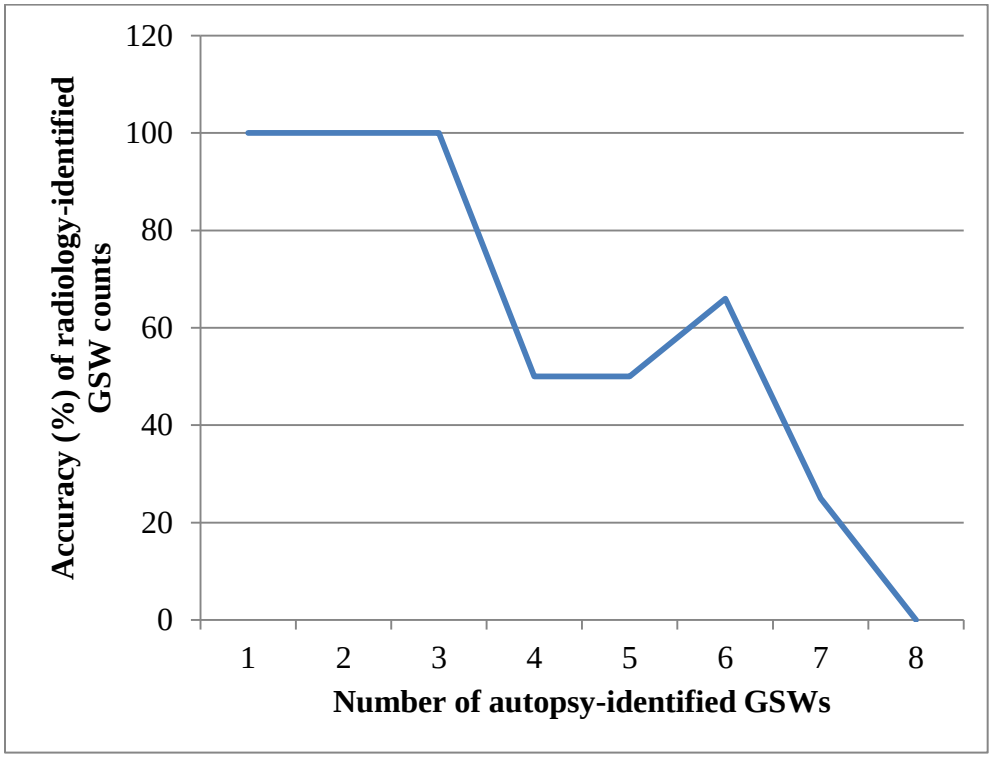


Table 21: Demographics of single gunshot wound decedents (n=176)

Characteristic	Number	Percentage
Gender		
Male	157	89.2
Female	19	10.8
Race/ethnicity		
White non-Hispanic	201	59.7
White Hispanic	56	31.8
American Indian	7	4
African American	5	2.8
Asian/Pacific Islander	2	1.1
Unknown	1	0.6

Table 22: Mean number of injuries described by autopsy and PMCT in single gunshot wound deaths

Mean number of findings described, single GSWs (n=176)						
Technique	**Mean**	**Std Dev**	**N**	**Minimum**	**Maximum**	**Median**
Autopsy	8.29	3.4	176	2	17	8
PMCT	9.96	3.6	176	0	23	10

Table 23: Mean ISS assigned by autopsy and PMCT for single GSW deaths

Mean ISS assigned, single GSWs (n=176)						
Technique	**Mean**	**Std Dev**	**N**	**Minimum**	**Maximum**	**Median**
Autopsy	44.3	23.6	176	10	75	30
PMCT	43.2	22.3	176	1	75	29

Table 24: Kappas for MAIS assigned by autopsy and PMCT by region, single GSWs

Single GSWs: MAIS kappas between autopsy and PMCT	Kappa	Level of agreement
Head	0.74	Substantial
Face	0.3	Fair
Chest	0.7	Substantial
Abdomen	0.47	Moderate
Extremities	0.66	Substantial
External	-0.01	Poor

Table 25: Entry wound comparisons for single GSWs

Entry wound matched?	Frequency	Percent
No	16*	9.1
Yes	160	90.9

*In the 16 cases where the entry wound determination did not match between autopsy and PMCT, the entry as described by autopsy was determined to be correct

Table 26: Exit wound comparisons for single GSWs

Exit wound matched?	Frequency	Percent
No	13*	7.4
Yes	138	78.4
NA**	25	14.2

*In the 13 single GSWs where exit determination did not match, the exit wound described by autopsy was determined to be correct in 12 deaths (6.8%), and the exit wound described by CT was determined to correct in one death (0.6%)

**Large exit areas in these cases, such as entire top of head, rather than a single discrete exit wound

Table 27: Trajectory assessment of single gunshot wounds

Trajectory	Number	Percent
Up/down		
Matched	139	79
If not a match:		
Autopsy correct	34	91.9
PMCT correct	1	2.7
Neither correct	1	2.7
NA	1	2.7
Front/back		
Matched	127	72.2
If not a match:		
Autopsy correct	48	98
PMCT correct	1	2
Left/right		
Matched	149	84.7
If not a match:		
Autopsy correct	27	100
PMCT correct	0	0

Table 28: Assessment of re-entry wounds from a single bullet

Re-Entry Wounds	Number	Percent
Re-Entry Wound (n=2)		
Matched	1	50
Autopsy correct	1	50
Re-Entry Exit		
Matched	1	50
Autopsy correct	1	50
Re-Entry Up/down		
Matched	2	100
Re-Entry Front/Back		
Not matched	2	100
Autopsy correct	2	100
Re-Entry left/right		
Matched	2	100

Table 29: Total injury counts for single gunshot wound deaths

Autopsy GSW injuries total	PMCT GSW injuries total	Total Injuries	Matched 1:1	Matched >1:1	Total coded as matches	% of total findings
1,493	1,753	3,246	881	346	2,108	64.9%

Unique findings*	GSW R1	R1%	GSW R2	R2%	GSW A1	A1%	GSW A2	A2%
2,365	359	15.2	169	7.1	397	16.8	213	9

*Total findings-one set of duplicate matches (3,246-881=2,365)

Table 30: Demographics of multiple gunshot wound fatalities (n=27)

Characteristic	Number	Percentage
Gender		
Male	21	77.8
Female	6	22.2
Race/ethnicity		
White non-Hispanic	6	22.2
White Hispanic	19	70.4
American Indian	2	7.4

Table 31: Mean number of gunshot wounds found by autopsy and PMCT

Variable	Mean	Std Dev	N	Minimum	Maximum	Median
Number of GSWS: Autopsy	4.3	2.0	27	2	8	4
Number of GSWS: PMCT	3.9	2.0	27	2	8	3

Table 32: Mean ISS assigned by autopsy and PMCT, multiple GSWs

Variable	N	Mean ISS	Std Dev	Sum	Minimum	Maximum
ISS assigned by autopsy	27	40.3	17.7	1087	17	75
ISS assigned by PMCT	27	39.7	17.7	1072	16	75

Table 33: Mean number of injuries detected by autopsy and PMCT, multiple GSWs

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Autopsy findings	27	15.6	4.9	7	23	16
PMCT findings*	27	17.9	7.8	6	36	15

*Significant difference in means (p=0.02)

Table 34: Findings by autopsy and PMCT for multiple GSWs

Autopsy GSW findings total	PMCT GSW findings total	Total Injuries	Matched	Matched >1:1	Coded as match	Percent
420	483	903	235	104	574	63.6

Unique injuries	GSW R1	R1%	GSW R2	R2%	GSW A1	A1%	GSW A2	A2%
668	113	16.9	47	7	123	18.4	46	6.9

Table 35: Kappa statistics by region for MAIS scores, multiple GSWs

Multiple GSWs: MAIS kappas between autopsy and CT	Kappa	Level of agreement
Head	0.24	Fair
Face	0.39	Fair
Chest	0.61	Substantial
Abdomen	0.61	Substantial
Extremities	0.51	Moderate
External	0.15	Slight

Table 36: Evaluation of wound parameters in multiple GSWS by PMCT

Wound parameter	Number	Percent
Entry wound matched between autopsy and PMCT	73/107	68.2
Exit wound matched	66/104	63.5
Trajectory matched		
Up Down	47/107	43.9
Front Back	62/107	57.9
Left Right	53/107	49.5

C. Pediatric Trauma deaths (n=63)

Table 37: Demographics of pediatric trauma deaths

Characteristic	Number	Percentage
Gender		
Male	40	63.5
Female	23	36.5
Manner of death		
Homicide	12	19
Accident	51	81
Race/ethnicity		
White non-Hispanic	23	36.5
White Hispanic	23	36.5
American Indian	17	27
Mean age in years		
Males	1.35	
Females	1.74	
Overall	1.58	

Figure 7: Age distribution by gender of pediatric trauma decedents

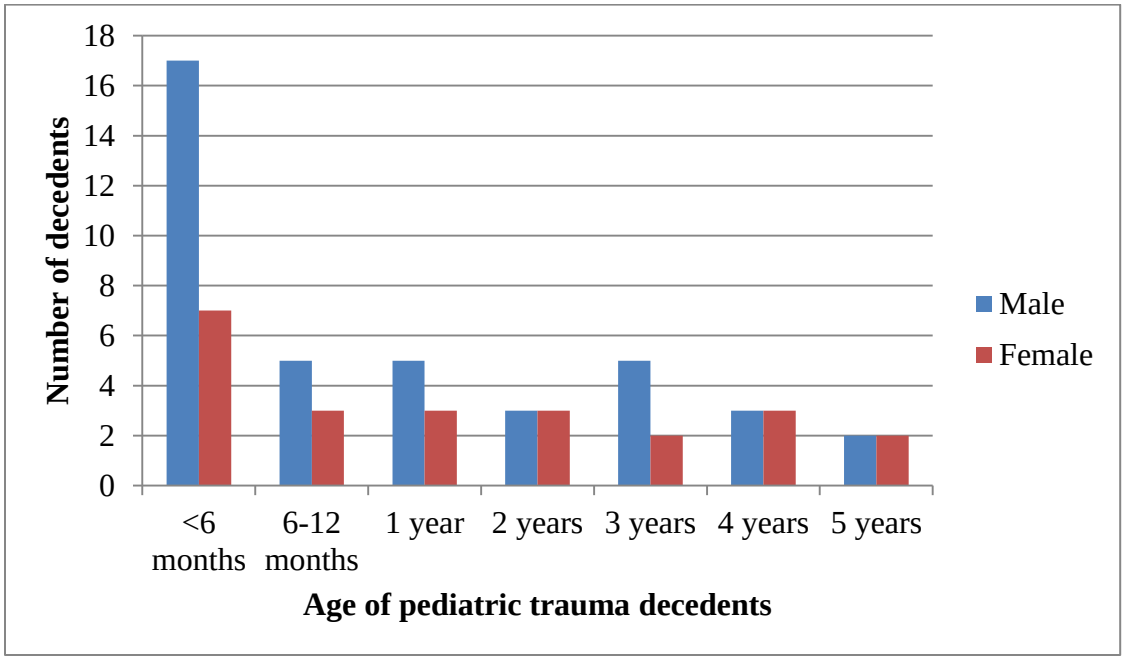


Table 38: Mechanism of injury in pediatric trauma deaths

Mechanism of injury	Frequency	Percent
Co-sleeping	10	15.9
Suffocated	11	17.5
Beaten	9	14.3
MVA	8	12.7
Drowning	6	9.5
GSW	3	4.8
Pedestrian struck by MV	3	4.8
Wedging	3	4.8
Choking	3	4.8
ATV	1	1.6
Crushed by TV	1	1.6
Crushed by boards	1	1.6
Fell down well	1	1.6
Hyperthermia	1	1.6
Mauled by dog	1	1.6
Mom in MVA, premature birth	1	1.6

Table 39: Cause of death comparison between autopsy and PMCT

Cause of death	Number	% of total
Both correct	51	81
Both incorrect	0	0
Autopsy correct, PMCT incorrect	11	17.5
Autopsy incorrect, PMCT correct	1	1.6

Table 40: Injury counts by AIS region for autopsy and PMCT, pediatric trauma

AIS Region	Autopsy # of findings	CT # of findings	Total findings	# of 1:1 matches	Unique findings (total-1:1 match)
Head	143	111	254	59	195
Face	19	11	30	6	24
Chest	60	86	146	21	125
Abdomen	42	23	65	11	54
Extremities	24	28	52	17	35
External	83	20	103	19	84
Total	**371**	**279**	**650**	**133***	**517**

*There were five findings coded as multiple matches

Table 41: Missed injuries by AIS region, Pediatric Trauma Cohort

Region	R1 count	R1 % of total	R2 count	R2 % of total	A1 count	A1 % of total	A2 count	A2 % of total
Head	65	33.3	16	8.2	40	20.5	12	6.2
Face	7	29.2	6	25	4	16.7	0	0
Chest	25	20	11	8.8	43	34.4	22	17.6
Abdomen	28	51.9	1	1.9	10	18.5	1	1.9
Extremities	6	17.1	0	0	9	25.7	2	5.7
External	41	48.8	27	32.1	3	3.6	0	0
Total	**172**	**33.3**	**61**	**11.8**	**109**	**21.1**	**37**	7.2

Table 42: Comparison of ISS assigned by autopsy and PMCT, pediatric trauma deaths

ISS Comparison	Number	Percent
ISS matched within 1	32	50.8
Autopsy ISS more severe	22	34.9
PMCT ISS more severe	9	14.3

Table 43: Kappa statistics for MAIS by region in pediatric trauma deaths

Region	Kappa for MAIS by region	Agreement
Head	0.34	Fair
Face	0.48	Moderate
Chest	0.49	Moderate
Abdomen	0.39	Fair
Extremities	0.75	Substantial
External	0.21	Fair

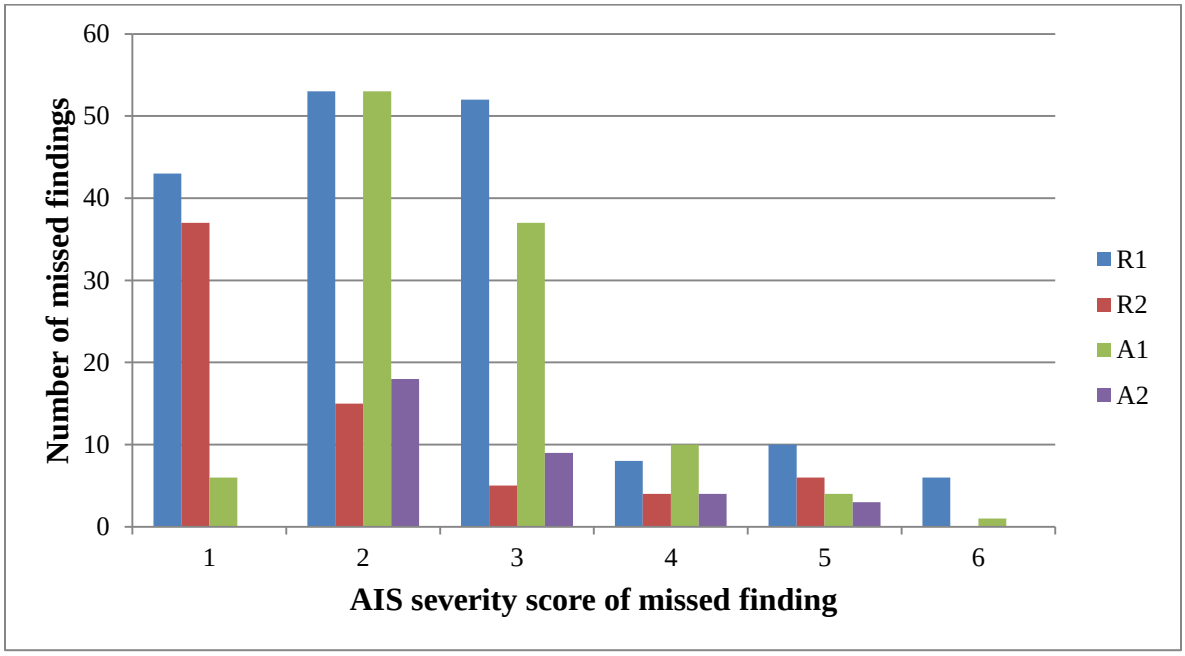
Table 44: Most commonly missed findings at autopsy in pediatric trauma deaths

Findings coded as A1 (missed on autopsy)	Number	Findings coded as A2 (would not expect to have seen at autopsy)	Number
Intraventricular hemorrhage	9	Pneumothorax	13
Pulmonary contusions	8	Pneumocephalus	9
Thoracic vertebrae compression fx	8	Pneumopericardium	5
Cerebral edema	7	Pneumomediastinum	2
Intraparenchymal hemorrhage	5	Transverse process fx, thoracic vertebrae	2
Subarchnoid hemorrhage	5	Ulna fracture	1
Bullet fragments in thoracic vertebral body	4	Humerus fracture	1
Pulmonary contusions	4	Transverse process fx, lumbar vertebrae	1
Hemothorax	4	C1 posterior ring fx	1
Pulmonary lacerations	4	Ethmoid fx	1

Table 45: Most commonly missed findings on PMCT in pediatric trauma deaths

Findings coded as R1 (missed on PMCT)	Number	Findings coded as R2 (would not expect to have seen on PMCT)	Number
Contusions, external	25	Abrasions, external	28
Subdural hematoma	21	Diaphragmatic contusions	4
Subarchnoid hemorrhage	14	Pleural lacerations	2
Cerebral edema	5	Cervical nerve root hemorrhages	2
Lung contusions	4	Asphyxia	2
Hemothorax	4	Periorbital ecchymoses	1
Cerebellar contusion	3	Subdural hematoma	1
Asphyxia	3	Bilateral hemorrhages, optic nerve sheaths	1
Multiple rib fractures	3	Contusion, inferior vena cava	1
Atlanto-occipital dislocation	2	Lacerated pericardium	1

Figure 8: Distribution of AIS severity scores for missed findings, pediatric trauma deaths



D. Drug Poisoning Deaths (n=457)

Table 46: Demographics of drug poisoning decedents

Demographics	Number	Percent
Gender		
Male	307	67.2
Female	157	32.8
Race/ethnicity		
White non-Hispanic	232	50.8
White Hispanic	167	36.5
American Indian	50	10.9
African American	6	1.3
Asian/Pacific Islander	2	0.44
Manner of death		
Accident	234	51.2
Natural	148	32.4
Suicide	46	10.1
Homicide	3	0.66
Undetermined	26	5.7
Age in years		
Range	15-90	
Median	50	
Male mean	47.6	
Female mean	50.3	

Figure 9: Age distribution by gender of drug poisoning deaths

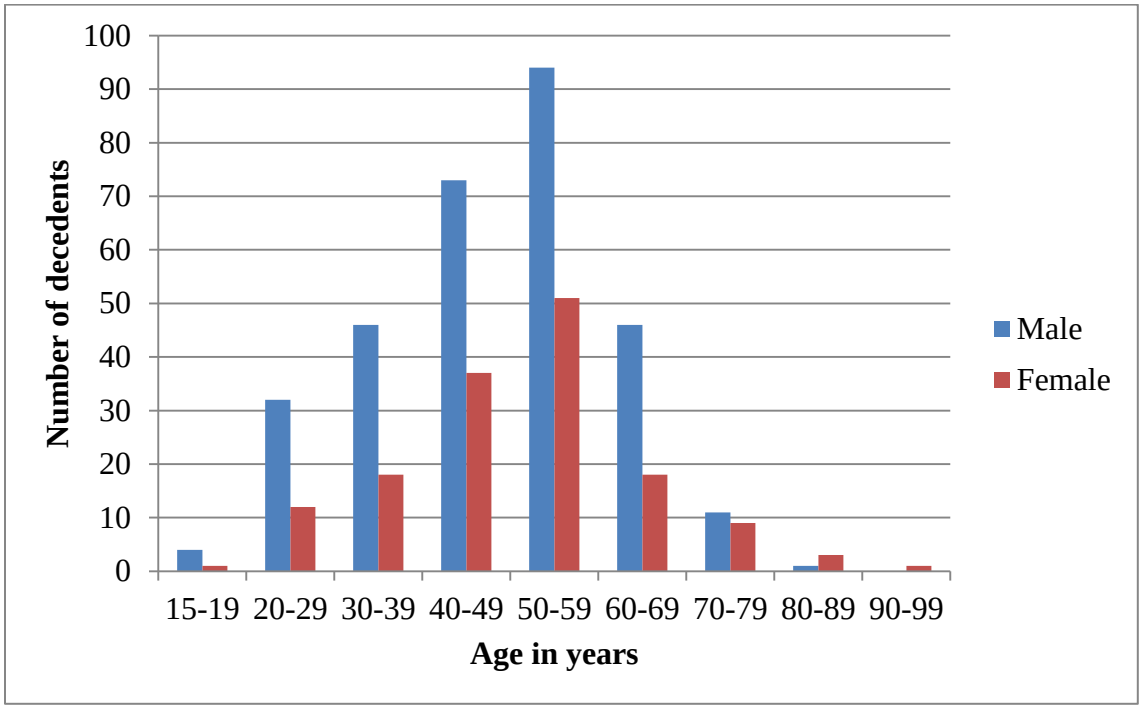


Table 47: Findings by original autopsy and PMCT in drug poisoning deaths

Total findings Autopsy	Total findings PMCT	Total findings	Total matches	Total-matches-non-relevant findings*
6238	3571	9809	939	6182

Total-matches-non-relevant findings*	R1	R1%	R2	R2%	A1	A1%	A2	A2%
6182	1438	23.2	1902	30.7	948	15.3	955	15.4

***Subtracted x codes (non-relevant finding) and p codes (primary diagnoses)**

Table 48: Agreement between MAIS assigned by autopsy and PMCT by region in drug poisoning deaths

AIS Region	Kappa	Level of agreement
Head	0.37	Fair
Face*	-0.004	Poor
Chest	0.13	Slight
Abdomen	0.14	Slight
Extremities*	-0.004	Poor
External	0.1	Slight

*Very few cases with injuries in these regions

Table 49: Mean numbers of findings and ISS scores by autopsy and PMCT

Evaluation	Mean number of findings	St. dev	Mean ISS	St. dev
Original autopsy	13.6*	7.14	1.18	3.57
PMCT	7.8	4.98	1.19	4.08

*Significantly different, p<0.0001

Figure 10: Injury Severity Scores compared between autopsy and PMCT

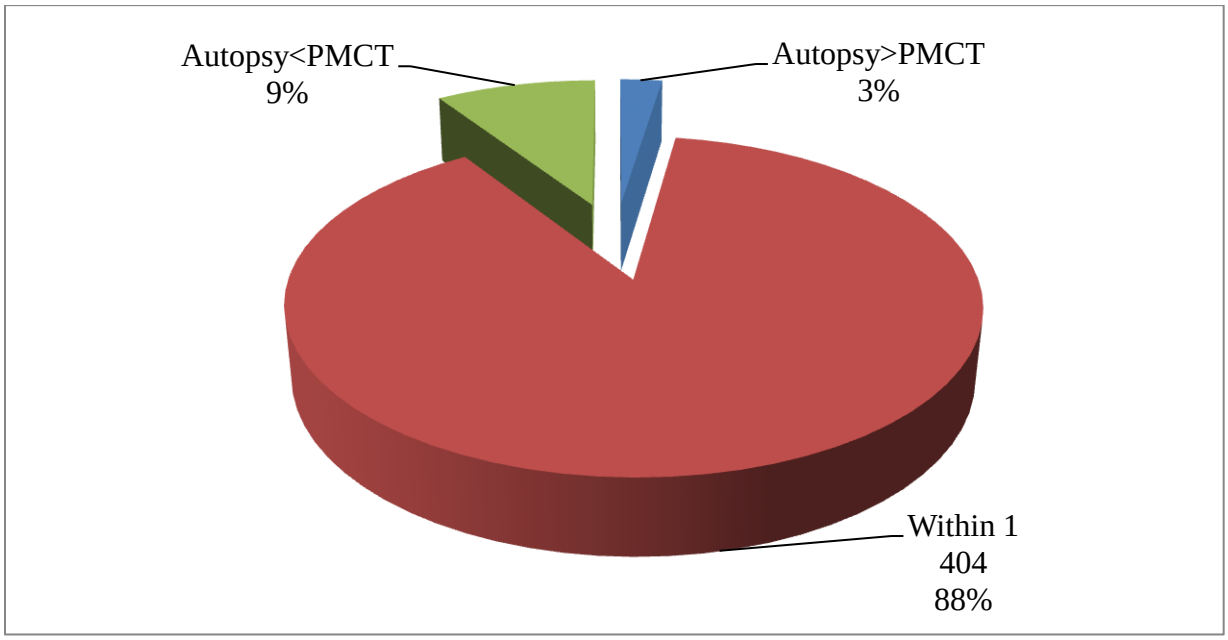


Table 50: Cause of death comparisons between original autopsy (death certificate) and reviewing pathologist's cause of death

Cause of death, comparing DC to review	Matched & correct	%	Autopsy/DC correct	%	Reviewer correct	%	Neither correct	%
Part 1								
Line 1	356/457	77.9	98/101	97	2/101	1.9	1/101	0.1
Line 2	13/38	34.2	25/25	100	NA	NA	NA	NA
Line 3	5/8	62.5	3/3	100	NA	NA	NA	NA
Line 4	3/3	100	NA	NA	NA	NA	NA	NA
Part 2								
Line 1	122/169	72.2	45/47	95.7	0	0	2/47	4.3
Line 2	30/65	46.2	33/35	94.3	2/35	5.7	0	0
Line 3	16/25	64	8/9	88.9	1/9	11.1	0	0
Line 4	4/4	100	NA	NA	NA	NA	NA	NA
Line 5	0	0	1/1	100	NA	NA	NA	NA

Table 51: Comparison of cause of death statements in people younger than 40 to those of people age 40 and over in the drug poisoning cohort

Cause of death, comparing DC to review	Under 40, match & correct	%	DC correct	%	40 and older, match & correct	%	DC correct	%	Review correct	%	Neither correct	%
Part 1												
Line 1	97/113	85.8	16/16	100	259/344	75.3	82/85		2/85		1/85	0.01
Line 2	1/1	100			12/37		24/25		1/25			
Line 3	NA				5/8		3/3	100				
Line 4	NA				NA							
Part 2												
Line 1	17/27	63	10/10	100	105/142	74	37/37	100				
Line 2	3/6	50	3/3	100	27/59	45.8	31/32		1/32	3.1		
Line 3	NA				16/25	64	8/9		1/9	11.1		
Line 4	NA				4/4	100						
Line 5	NA				0/1	0	1/1	100				

Table 52: Findings most often missed at autopsy in drug poisoning deaths

Findings coded as A1 (Missed on PMCT)	Number	Findings coded as A2 (would not expect to have seen on PMCT	Number
Calcifications, intracranial	118	Vascular calcifications at the carotid bifurcations	161
Calcifications, coronary artery	104	Degenerative changes	134
Fractures, prior to resuscitation	55	Fractures, prior to resuscitation	114
Fractures (rib and/or sternum), due to resuscitation	38	Osteoarthritis	95
Nephrolithiasis	32	Status post-op, extremity surgery	38
Aspiration pneumonitis	26	Compression fracture, vertebral column	33
Aspiration	25	Fractures with hardware	25
Diverticulosis	24	Calcifications, coronary artery	24
Hernia	22	Idiopathic skeletal hyperostosis, diffuse	12
Atherosclerotic calcification in the aorta	20	Contusions, external	11

Table 53: Findings most often missed on PMCT in drug poisoning deaths

Findings coded as R1 (Missed on PMCT)	Number	Findings coded as R2 (would not expect to have seen on PMCT)	Number
Contusions, external	200	Substance present on toxicology (illicit, prescription, carbon monoxide, and/or ethanol)	436
Cardiomegaly (heart weight equal to or greater than 400 grams)	168	Abrasion, external	260
Obesity	84	Atherosclerotic stenosis	210
Edema, pulmonary	45	Hepatitis	56
Status post-op, appendectomy	42	Cardiomegaly (heart weight equal to or less than 399 grams)	54
Cirrhosis	39	Stenosis	51
Coronary artery disease	35	Left ventricular hypertrophy	51
Atherosclerosis, aorta	34	Track marks	48
Arteriolonephrosclerosis	32	Adhesions	34
Stenosis	29	Emphysema	27

IV. Conclusions

1. Discussion of findings

Across all four cohorts of this study, blunt force injury, firearm fatalities, pediatric trauma and drug poisoning deaths, it was evident that both autopsy and PMCT can separately arrive at the same cause of death for given decedent. In 85% of blunt force injury deaths, 99.5% of firearm fatalities, 81.4% of pediatric trauma deaths, and up to 78% of drug poisoning deaths, the cause of death assigned by PMCT was determined to be correct and the same as that assigned by autopsy. In most, but not all, of the cases where the cause of death did not match between autopsy and PMCT, the autopsy cause of death was assessed as the correct one, in 10% of blunt force injury deaths, 1.5% of firearm fatalities, 17% of pediatric trauma deaths and 89-100% of drug poisoning deaths. Previous studies have found that PMCT performs better in non-natural deaths (52), offering insight into the higher rates of agreement in blunt force injury and firearm fatalities. The most common cause of death in the pediatric trauma deaths was suffocation, with no traumatic injuries present and the drug poisoning deaths similarly had significant amounts of natural disease present but very few traumatic injuries. Evidence from these study cohorts would support PMCT being used to supplant autopsy in regard to cause of death determination in blunt force and some firearm deaths, particularly when used in conjunction with external examinations and toxicologic evaluations.

The assessment of the combined severity of the injuries cataloged, as measured by the Injury Severity Score (ISS), was similar in the blunt force and firearm deaths, with 21% and 32.5% of the deaths resulting in the same ISS by both techniques, and the remaining deaths about evenly distributed between a higher PMCT ISS and a higher autopsy ISS. In pediatric trauma deaths, however, the autopsy ISS was within one point of the PMCT ISS in 51% of the deaths,

and was likewise within one point of the PMCT ISS in 88% of drug poisoning death. A previous study had detected a higher level of agreement (no or moderate variation), 85%, when comparing PMCT-assigned ISS to those assigned by autopsy in 52 traffic fatalities, higher than was seen in three of our four cohorts. The highest level of ISS agreement in our study was seen in the drug poisoning cohort, where most of the findings were natural disease rather than traumatic injuries. It was notable that while all decedents included in the study had perished from their injuries, most of them (66-90% depending on cohort and technique) did not end up with a "non-survivable" ISS of 75, indicating the need for the appropriate context for interpreting ISS and AIS scores in decedents, as the system is intended for use in live patients but is the best option for objectively scoring trauma injuries (32).

For each decedent, the most severe injury by region was abstracted and recorded as the maximal AIS (MAIS) score. Comparing these scores for each decedent by region (MAIS assigned by PMCT compared to MAIS assigned by autopsy) found mostly moderate to substantial agreement between the two techniques, depending on region. Understandably, as radiologists were not able to perform an external examination, the least amount of agreement between autopsy and PMCT occurred in the external region, with kappa values ranging from 0.03 for firearm fatalities to 0.2 for pediatric trauma deaths in regard to the external region. Overall, the drug poisoning cohort had the worst levels of agreement in MAIS scores, with poor agreement in the face and extremities and only fair agreement in the head, with slight agreement in the chest, abdomen and external region. The best agreement for MAIS scores was seen in the firearm fatalities, with substantial agreement in the head and chest and moderate agreement in the abdomen and extremities. Lower levels of agreement were seen in the blunt force and pediatric trauma deaths, with only fair agreement in the head and abdomen and moderate

agreement in the chest. Leth and Ibsen found higher levels of agreement (0.6 and greater) in their study of traffic fatalities, with moderate to substantial agreement between MAIS scores for all regions studied (34). We only found this level of agreement in the head, chest and abdomen of firearm fatalities and the extremities in pediatric trauma decedents. None of the regions in either blunt trauma or drug poisoning deaths rose above a kappa of 0.47 (moderate agreement) when comparing MAIS scores assigned by PMCT and autopsy.

Looking at numbers of injuries detected, PMCT detected significantly more injuries than autopsy in both the blunt force injuries and the firearm fatalities arms of the studies, though autopsy detected more injuries than PMCT in the pediatric trauma and drug poisoning arms, the two cohorts with the most cases where no traumatic injuries were present. Leth and colleagues found that radiologists diagnosed more injuries overall in traffic fatalities, similar to our result that PMCT detected more injuries in the fatalities with more acute injuries present (blunt force and firearms) (35). The percentage of injuries coded to be a match between autopsy and PMCT was 46.6% for blunt force deaths, 38.4% for drug poisoning deaths, and 41.7% for pediatric trauma deaths, but 64.9% for firearm fatalities. The percentage of unique injuries seen on autopsy which should have been detected on PMCT but were not ranged from 15.2% for the firearm fatalities to 33% in the pediatric trauma deaths. The percentages of injuries which were ruled to be below the imaging resolution of the CT scan ranged from 6.2% of unique injuries in the blunt force deaths to 30.7% in drug poisoning deaths. The percentages of injuries seen on PMCT but missed on autopsy and should have been detected were very comparable between the blunt force injury and pediatric trauma deaths (21.2% and 21.5%, respectively). The percentage was lower for firearm fatalities (16.8%) and drug poisonings. The percentage of injuries seen on PMCT but determined to be outside the routinely dissected areas of an autopsy was highest in the

blunt force injury deaths (19.1%), followed by drug poisoning deaths (15.4%) and lower for both the pediatric trauma and firearm fatalities (7.4% and 9%, respectively).

When assessing how well PMCT functions in assessing firearm fatalities, the overall parameters were encouraging, with excellent agreement in both cause of death determination and MAIS scores. Radiology detected up to three gunshot wounds with 100% accuracy, and correctly identified the entry wound in 91% of all single gunshot wound fatalities. The exit wound was correctly identified in 91% of the deaths where there was a discrete entry wound (excluding those cases where a shotgun was used, resulting in a large part of the head or body missing rather than a single exit wound). In one case, the exit wound identified by PMCT was determined to be the correct exit, rather than the one identified on autopsy. PMCT also performed respectably when assessing a bullet's trajectory through the body, correctly identifying the up/down axis in 79% of single gunshot wound fatalities, the front/back axis in 72% of single GSW deaths, and the left/right axis in 85% of single GSW cases. Assessment of re-entry of a single bullet was more difficult, but could only be attempted in two of the deaths. Even in multiple gunshot wound deaths (where the decedent suffered from two to eight separate gunshot wounds), 64% of the findings were a match between autopsy and PMCT, and MAIS scores indicated fair (head, face) to substantial (chest, abdomen) agreement by region. The wound parameters were more challenging to assess with multiple, intersecting injury tracts, but PMCT correctly identified entry wounds 68% of the time, and exit wounds 64% of the time. Trajectories were more challenging to assess with the multiple wounds, with only 44%-58% correctly identified. With multiple gunshot wounds, it would be difficult to adequately describe the trajectories, and not advisable to supplant autopsy with PMCT. In single gunshot wounds, it performed well and could be used to assess entry and exit wounds. Further information would be needed to improve

the determination of trajectory, but this could also be a factor of inexperience on the radiologists' part, as they have not had the training and experience in trajectory determination of the forensic pathologists.

Reviewing the types of injuries most commonly missed by autopsy and PMCT, the most commonly missed findings on autopsy, which in the opinion of the reviewing consensus physicians should have been detected, are very similar between blunt force, firearm and pediatric trauma deaths and most frequently involve hemorrhage. Intraventricular hemorrhage was the finding most often seen on PMCT which was either not found or not noted on autopsy across all three types of death. Subdural and subarchnoid hemorrhages, facial fractures, and cerebral edema were also among the ten most commonly missed findings on autopsy, similar to previous studies (35, 53). Other commonly missed findings seen on PMCT and not seen on autopsy included gas accumulations such as pneumothorax and pneumocephalus and vertebral body fractures, which were determined to be out of the scope of routine autopsies. Not surprisingly, external contusions and lacerations were the most commonly missed finding on PMCT across these three cohorts, but the most common radiology misses also included hemothoraces, lung and liver lacerations and atlanto-occipital dislocations.

The picture for the drug poisoning deaths for missed findings differed substantially from the previous three cohorts. In these deaths, autopsy most frequently missed calcifications, both intracranial and in coronary arteries, fractures, nephrolithiasis and aspirations. Radiology most frequently missed external contusions, as in the previous cohorts, but then missed obesity, pulmonary edema, cirrhosis and atherosclerosis. With very few acute injuries and significant incidence of natural disease, drug poisoning deaths are challenging for approaching as PMCT-only. Deaths that present initially as potential drug poisoning are often ultimately attributed to

natural disease or an interplay between natural disease and drugs, especially in people over the age of 40, where the presence of natural disease can create challenges in determining cause of death. Nevertheless, in this age group, pathologists using PMCT and scene investigation data correctly identified the cause of death in only 74.7% of the deaths. In people under the age of 40, the use of PMCT without information from the internal examination done at autopsy resulted in 86% correct cause of death determinations a figure similar to the blunt force injury and pediatric trauma cohorts.

It is apparent that in all four types of deaths studied, both autopsy and PMCT are imperfect and missed injuries. Sensitivity was respectable but not perfect for either technique, ranging from a low of 61.2% for radiology in pediatric trauma deaths to a high of 84.2% for autopsy in single gunshot wounds. Neither one was perfect in detecting all injuries present in a decedent, challenging the long-held belief of autopsy as the gold standard for injury detection. Ideally, both techniques would be used in tandem, particularly in suspected cases of child abuse and firearm and blunt force homicides, where a full cataloging of injuries is imperative. Given the high percentages of agreement in cause of death determination, and moderate to substantial agreement in assessment of injury severity both by region and overall, PMCT could be used to supplant autopsy, particularly if a full external examination is completed in concert with a rigorous PMCT interpretation by a radiologist familiar with post-mortem scans (52).

2. Implications for policy and practice

In an ideal world, all medical examiners would have access to not only a CT scanner, but an experienced radiologist to interpret the results from the scans for them. Our results indicate that autopsy misses injuries that can only be seen on PMCT for 17% to 21% of all injuries in decedents whose deaths are due to firearm fatalities, pediatric trauma or blunt force injuries. In a small but not-non-existent percentage of studied cases (1.5%-3.6%), the autopsy-assigned cause of death was found to be incorrect, a finding that would not have been revealed without the information from the PMCT and a review of the case by a panel of study pathologists and radiologists. In the majority of cases included in this study, PMCT could supplant autopsy in cases of family, religious or cultural objections, particularly when paired with a thorough external examination (52).

This study was not without its challenge and limitations. We had originally designed the study where radiologists and pathologists would assign AIS scores to their reports of findings. This was not feasible, and necessitated the hiring of a certified-AIS coder, the development of methods to redact reports and submit them to her, and set up a multi-user REDCap database designed to have data entered from both OMI and the coder's location (Texas). This process resulted in a much more robust end product, but added to the associated costs. We also needed, but had not planned for, a supervising radiologic technologist. Not only did this individual supervise the conduct of all PMCT scans, she also performed case identification and tracking, quality assurance for each scan, and prepared all autopsy and radiology reports to be sent to the appropriate reviewers and coders. This required significant amounts of her time, and required a high level of organizational and data management skills. She was also instrumental in ensuring radiologists completed their reviews of scans, entering data during consensus conferences and

resolving any discrepancies that arose in case counts. If this study were to be repeated, funding would be requested for a full-time supervising radiologic technologist, as this study placed tremendous burdens on her in addition to her routine tasks and responsibilities.

The time needed to complete this study was also underestimated. Radiologists found it challenging to review study scans in addition to the demands of their clinical service, and often could not complete reviews in a timely manner. Fewer pathologists and radiologists were available to attend consensus conferences, causing us (with NIJ permission) to reduce the review teams from two pathologists and two radiologists to one of each. The consensus conferences also took more time per case than we had anticipated, extending the course of the study. The poisoning cohort was particularly challenging, with changes in coding and loss of OMI staff. Trying to schedule radiologists and pathologists to meet for two- to three-hour consensus conferences was a challenge, and the conferences would sometimes have to be postponed due to clinical obligations. Several pediatric radiologists who originally agreed to assist with the study later declined, making it difficult to replace them and find other radiologists with similar expertise and who were available to interpret PMCT scans when needed.

Unfortunately, another challenge arose in regard to the pediatric trauma death cohort. Eleven of the enrolled cases were unblinded when two OMI non-study pathologists chose to disregard the blinding and review the PMCT results in order to write their autopsy reports. These cases had to be excluded. Additionally thermal deaths had to be excluded as well (seven blunt force deaths, two pediatric deaths and two firearm fatalities) as it was impossible to determine which injuries were due to thermal damage rather than firearms or trauma.

As with most large scale studies, more time, more money and more personnel were ultimately required to complete the planned objectives than had ever been anticipated in our planning stages.

3. Implications for further research

We will be happy to share our "lessons learned" with anyone else attempting a similar study**.** Our results are one piece of the emerging information regarding how best to utilize radiologic imaging in forensic pathology, and continued study is needed. The demographics and mechanisms of death included in this study are comparable to OMI's usual decedent case load (36) but may not be similar to other locations. A second set of consensus conferences would be helpful to review all injuries on a scale of significance, as "missed" injuries that should have been seen may not have contributed to death or been relevant to ultimately understanding and describing the cause of death. Natural disease, as seen in the 460 drug poisoning deaths, is challenging to catalog and compare in the same way the traumatic and firearm injuries are handled.

Ideally, consensus conferences would be held the day a case was autopsied. Autopsy and PMCT results could be reviewed and assessed soon after the procedures were performed, and information could be obtained regarding the true negative findings and the false positives. With the way in which we assessed the coded reports, we were not able to determine which injuries were false positives.

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VI. Dissemination of Research Findings

Gerrard CY*, Lathrop SL, Hatch GM, Williamson S, Price JP, Lopez KM, Andrews SW, Zumwalt RE, Paul ID, Elifritz J, Nolte KB. Postmortem Computed Tomography (PMCT) in pediatric deaths attributed to asphyxia. Oral presentation, International Society for Forensic Radiology and Imaging Annual Conference, Leicester, England, May 12, 2015.

Hatch GM*, Lathrop SL, Gerrard CY, Elifritz J, Cushnyr BW, Mlady G, Pohl J, Andrews SW, Paul ID, Price JP, Zumwalt RE, Wiest PW, Nolte KB. Comparison of postmortem x-ray computed tomography (CT) and autopsy in gunshot wound fatalities. Oral presentation, International Society for Forensic Radiology and Imaging Annual Conference, Leicester, England, May 15, 2015.

Lathrop SL, Hatch GM, Gerrard CY, Williamson S, Price J, Lopez KM, Andrews SW Zumwalt RE, Paul ID, Elifritz J, Nolte KB*. A prospective double-blinded comparison of autopsy and post-mortem computed tomography (PMCT) for the evaluation of pediatric trauma deaths. Oral presentation, American Academy of Forensic Sciences 2015 Annual Meeting, Orlando FL, February 19, 2015.

Nolte KB*, Lathrop SL, Hatch GM, Gerrard CY, Elifritz J, Cushnyr BW, Mlady G, Pohl J, Andrews SW, Paul ID, Price JP, Zumwalt RE, Wiest PW. Utility of postmortem x-ray computed tomography (CT) for medicolegal autopsies on decedents with blunt force injuries. Oral presentation, 20th World Meeting of the International Association of Forensic Sciences Annual Conference, Seoul, South Korea, October 17, 2014

Cushnyr BW*, Lathrop SL, Hatch GM, Gerrard CY, Elifritz J, Andrews SW, Paul ID, Price JP, Zumwalt RE, Nolte KB. Utility of computed tomography (CT) as a postmortem tool for the diagnosis of blunt force head injuries. Poster, 20th World Meeting of the International Association of Forensic Sciences, Seoul, Korea, Oct 17, 2014.