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Improving and Evaluating Computed Tomography and Magnetic Resonance Imaging in the Investigation of Fatalities Involving Suspected Head Trauma

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Introduction: Autopsy is a well-established method, widely regarded as the gold standard for death investigation, both for legal purposes and to evaluate and improve clinical diagnosis. However, recent studies comparing Post-Mortem Computed Tomography (PMCT) imaging and Autopsy, by our institution and others, suggest that Autopsy+PMCT enhances the reliability of injury detection over that of autopsy alone. For example, in a recently published double-blinded study comparing PMCT and Autopsy in trauma cases, the number of unique injuries detected by combining Autopsy and PMCT findings was 20-40% greater than the number of injuries detected by either Autopsy or PMCT alone, suggesting that Autopsy+PMCT may someday be adopted as the new gold standard.. (Lathrop SL, Wiest PW, Andrews SW, Elifritz J, Price JP, Mlady GW, Zumwalt RE, Gerrard CY, Poland VL, Nolte KB. Can computed tomography replace or supplement autopsy? J Forensic Sci. 2023 Mar;68(2):524-535. doi: 10.1111/1556-4029.15217. Epub 2023 Feb 8. PMID: 36752321.) In the meantime, many questions remain to be addressed. When comparing Imaging and Autopsy findings, how is "agreement" best defined, what is the reason for "disagreement," and what are its implications? Is discordance worrisome, suggesting that neither Imaging nor Autopsy is performed with sufficient reliability or consistency? Or is discordance reassuring, demonstrating that Imaging and Autopsy each *reliably* provide unique information, resulting in a more comprehensive examination? If PMCT improves injury detection, will the further addition of Post-Mortem Magnetic Resonance Imaging (PMMRI), which is known to be more sensitive to soft tissue injury, result in a substantial improvement in the reliability of injury detection? *Our over-arching hypothesis is that the use of Advanced Radiological Imaging and Autopsy will result in death investigations that are demonstrably more comprehensive and reliable, particularly in cases for which complete injury documentation has legal importance, such as suspected abuse, medical malpractice, or workplace injury.*

In the studies reported here, we first systematically evaluated the accuracy of previous PMCT findings in cases of adult blunt force injury and pediatric trauma, to better define the causes and implications of observed discordance between PMCT and Autopsy. Second, we evaluated whether PMMR of the head and neck, in addition

to whole body PMCT, can further improve the radiological detection of injuries in fatalities involving suspected head trauma. The long-term goal of this research is to define best practices for effective and efficient integration of Advanced Radiological Imaging methods into the practice of Forensic Pathology.

I. Analysis of Autopsy-Radiology Discordance in Cases of Fatal Blunt Force Injury

Background: A previous double-blinded study (Lathrop et al.) compared the findings at autopsy, reported by a forensic pathologist, to the findings from whole body post-mortem CT (PMCT), reported by a clinical radiologist, for 167 cases of fatal blunt force trauma in adult subjects (18 years and older) and 67 cases of pediatric trauma (under 6 years of age). Lathrop et al. concluded that autopsy and PMCT are both imperfect at detecting injuries, but with similar overall sensitivities. Discordant findings identified in the previous study are defined to be those findings observed at autopsy but not PMCT ("radiology misses"), or those findings observed at PMCT but not at autopsy ("autopsy misses"). There are many potential explanations for discordance between autopsy and radiology, regarding a particular finding. A finding seen at autopsy may simply not be visible in the CT, or it may be an "undercall," i.e., visible at PMCT but overlooked by the radiologist. Similarly, a finding seen at radiology but not at autopsy may be a true finding that was overlooked by the pathologist, or it could be an "overcall" by the radiologist. An advantage of PMCT is that it allows for repeated interpretation by different observers, allowing a deeper understanding of errors. In contrast, repeating an autopsy is uncommon and not amenable to large research studies. Here, we present the results of a detailed analysis of discordant findings from the trauma cohorts (blunt force injury and pediatric trauma) originally studied by Lathrop et al. to better understand the nature and source(s) of discordance.

Review by 2nd Radiologist Methods: The whole body PMCT study for each case was reviewed by a 2nd radiologist, not involved in the previous study. The 2nd radiologist had a list of all discordant findings from the blunt force and pediatric trauma cohorts of Lathrop et al., including the injury descriptions and whether the finding was a miss at Autopsy or Radiology. The 2nd radiologist then rated each discordant finding as:

1. CT true miss (injury found at Autopsy is not visible in CT),
2. CT false miss (injury found at Autopsy is visible in CT but not recorded),

3. CT true find (injury missed at Autopsy is visible in CT),

4. CT false find (injury not found at Autopsy is not visible in CT),

5. Inconclusive (injury is ambiguous), or

6. Terminology Issue (same injury was found at both Autopsy and Radiology but described differently).

Results: A total of 2,830 discordant findings were reviewed. In 2,001 instances of autopsy-radiology discordance (71%), the 2nd Radiologist *agreed* with the 1st Radiologist's interpretation, including 696 CT True Misses (findings reported at autopsy that were not detectable at CT by either radiologist) and 1305 CT True Finds (findings missed at autopsy but detected at CT by both radiologists). In 521 instances of autopsy-radiology discordance (18%), the 2nd radiologist *disagreed* with the previous radiologist's interpretation, including 402 CT False Misses (findings reported at autopsy, missed by the previous radiologist, but seen by the second radiologist) and 119 CT False Finds (findings reported by the 1st radiologist, but not reported at autopsy and not seen by the 2nd radiologist). Additionally, the 2nd radiologist judged 225 previous instances of discordance (8%) to be inconclusive (*i.e.*, the finding was not sufficiently clear to assign it to another category), and 83 of the previous discordant findings (3%) were judged to be a disagreement in the terminology used, rather than true discordance.

The most common types of injuries that resulted in CT True Misses (findings seen at autopsy but not detected at PMCT by either radiologist) were external injuries (abrasions, contusions, and lacerations) and lacerations of organs (brain, heart, lung and other internal organs). The most common type of injury that resulted in CT True Finds (findings missed at autopsy but seen at PMCT by both radiologists) were fractures. More than 25% of all discordant findings analyzed were fractures missed at autopsy but found at PMCT by both radiologists. Fractures judged to be CT False Finds were extremely rare, representing < 1% of discordant findings. The most common Inconclusive findings involved internal organ injuries (hematomas and lacerations), followed by fractures. Fractures were also the most common injury classified as a "Terminology Issue."

Review by 3rd Radiologist Methods: In total, there were 746 findings where there was disagreement between the 1st and 2nd Radiologists categorized as CT False Miss, CT False Find, or Inconclusive. These 746 findings were reviewed by a 3rd Radiologist, who was not involved with any of the cases previously. The 3rd Radiologist had access to the previous observers' findings, including the ratings and comments of the 2nd

Radiologist. **Results:** CT False Misses: Of the 402 findings rated by the 2nd Radiologist as False Misses, the 3rd Radiologist agreed with the 2nd Radiologist that 305 of these findings were present (76% agreement). In the opinion of the 3rd Radiologist, in 42 cases, the 1st Radiologist was correct, and the finding was not present at PMCT. In 55 cases, the rating of the 3rd Radiologist was that the finding was Inconclusive (neither clearly present nor clearly absent), in disagreement with both the 1st and 2nd Radiologist. CT False Finds: Of the 119 findings rated as False Finds by the 2nd Radiologist, the 3rd Radiologist agreed that 80 of these findings were Overcalls (67% agreement). In the opinion of the 3rd Radiologist, in 20 cases, the 1st Radiologist was correct, and the finding was present. In 19 cases, the rating of the 3rd Radiologist was that the finding was Inconclusive (neither clearly present nor clearly absent), in disagreement with both the 1st and 2nd Radiologist. Inconclusives: Of the 225 findings rated Inconclusive by the 2nd Radiologist, the 3rd Radiologist concurred that 135 of these findings were Inconclusive (60% agreement). Of note, 103 of these findings rated Inconclusive by both the 2nd and 3rd Radiologists were reported by the 1st Radiologist but not observed at Autopsy. The agreement of the 2nd and 3rd Radiologist that these 103 findings were not clearly present, coupled with the absence of the finding at autopsy, suggests these findings may have been "overcalls" by the 1st Radiologist. Of the remaining 90 findings rated Inconclusive by the 2nd Radiologist, 73 were rated as "Present," 10 were rated as "Not Present," and 5 were rated as a "Terminology Issue" by the 3rd Radiologist. The remaining 2 Inconclusive findings appeared to be a match, namely a hemothorax observed at Autopsy and a hemothorax observed at PMCT, in the same subject, but which were not paired as a match in the original analysis. The 5 Inconclusive findings rated as a Terminology Issue by the 3rd Radiologist involved ambiguity or confusion regarding the injury description.

Summary and Conclusions: Overall, there was 71% agreement between the 1st and 2nd radiologist on the findings that were discordant between autopsy and radiology in the original analysis of Lathrop et al. We want to emphasize that the 2nd radiologist had the advantage of knowing the findings of the 1st Radiologist and the Autopsy findings. Thus, the agreement reported here is *not* intended to be a measure of interobserver agreement by two independent observers with equivalent prior knowledge, which would require a different

study design to assess. Rather, these data provide an estimate of how likely it is that a 2nd expert will agree with a finding reported by a 1st expert.

Of the 2,830 discordant findings reviewed by a 2nd Radiologist, 46% were findings missed at autopsy but detected by both the 1st and 2nd radiologist at PMCT, and 25% were findings observed at autopsy and not detected by either radiologist at PMCT. *These results demonstrate the complementarity of Autopsy and PMCT, and further strengthen the conclusions of Lathrop et al. that forensic pathology should consider the adoption of Autopsy+PMCT as the new Gold Standard.* The data further demonstrates some specific aspects of using PMCT in fatal trauma cases. Radiologists interpreting PMCT detect many fractures that would otherwise be missed if only an autopsy were performed, representing 25% of all discordant findings studied, and radiologists only rarely overcall fractures, with fracture overcalls representing <1% of all discordant findings studied. External injuries were the most common type of injury confirmed to be undetectable at PMCT, as noted by Lathrop et al., further highlighting the importance of the external exam in cases that will not receive an autopsy.

In total, there were 746 findings with disagreement between the 1st and 2nd Radiologists; these findings were further reviewed by a 3rd Radiologist. The overall agreement between the 2nd and 3rd Radiologists on the assigned rating for each finding was 70%, similar to the overall agreement between the 1st and 2nd Radiologist (71%) noted above. Again, this agreement is not a measure of interobserver agreement of independent observers with equivalent prior knowledge, because the 3rd Radiologist had access to all previous observers' findings.

II. Comparison of Post-Mortem Computed Tomography (PMCT) and Post-Mortem Magnetic Resonance Imaging (PMMRI) in Deaths involving Possible Head Trauma

Background: The results of Lathrop et al., comparing PMCT and Autopsy, suggest a role for PMMRI in improving the comprehensiveness of radiological evaluation of traumatic of the head and neck. For example, in the Blunt force injury cohort, of 913 unique head injuries identified by the combination of PMCT and Autopsy, 25% were missed at PMCT and 34% were missed at Autopsy; and the level of agreement between PMCT and Autopsy was only fair (kappa ~ 0.3) for the head and face. Because MRI is known to have a greater sensitivity to soft tissue pathologies, combining findings from PMCT and PMMRI is expected to reduce the frequency of

Radiology “misses” in the head and neck. Here we present the results of a double-blinded comparison of PMCT and PMMRI of the head and neck in medical examiner cases with possible head trauma.

Methods: Subject Selection: Decedents included in the study were Office of the Medical Investigator (OMI) cases, scheduled for a pathologist examination that day, with an unknown cause of death and either unknown circumstances (e.g., unwitnessed, found deceased outside of secure residence) or circumstances or history suggestive of possible blunt force injury (e.g., investigator report consistent with traumatic injury or a history of previous falls or seizures). Excluded were decedents with obvious fatal head or neck trauma, such as severe skull fractures or penetrating wounds of the skull, injuries which are easily appreciated at both external examination and at PMCT. Rather, the study focused on cases where it was not immediately apparent from the investigator’s report whether the decedent suffered a significant injury to the head, face, and/or neck, but it was a possibility; in these cases, the sensitivity of PMMRI may be useful in detecting soft tissue injuries that are below the detection threshold of PMCT. Imaging: First, a whole body PMCT study was performed on each decedent, as-received in the body bag, following standard OMI procedures: Siemens Definition Edge CT scanner with 64 detector rows, 120 kVp, automatic exposure, images reconstructed into 3 mm slices/3 mm overlap and 1 mm slices/0.5 mm overlap using both soft tissue and bone kernels). Other standard PMCT reconstructions included sagittal and coronal views of the whole body and the head/neck (both soft tissue and bone), a thin axial dental series, axial and coronal lung series, and a true brain series. The PMCT was reviewed by the imaging technologist to assess the safety of performing MRI. Metallic objects (jewelry, body bag zipper, etc.) were removed or moved out of the MRI field of view when possible. Following PMCT, the decedent temperature was measured (at the forehead using a non-contact digital thermometer), and a PMMRI study of the head and neck was then performed on a Siemens Symphony 1.5 T MR scanner using the pulse sequences summarized in the table below:

Pulse Sequence	Anatomy	Acquisition Type	TR (ms)	TE (ms)	Matrix	Pixel spacing (mm)	Slice Thickness (mm)
LOC	Head	GR	7	3	512	0.6	8
Echo Planar 2D Diffusion AXIAL	Head	EP	4200	106	192	1.2	5
T2 Turbo Spin Echo AXIAL	Head	SE	5000	92	512	0.45	5
T2 HEMO AXIAL	Head	GR	800	26	512	0.45	5
T2 Dark Fluid AXIAL	Head	SE/IR	8200*	85	512	0.45	5
T1 MPRAGE Isotropic AXIAL	Head	GR/IR	2200	3.3	256	1	1
T1 Turbo Spin Echo SAGITTAL	Head	SE	494	11	512	0.37	3
3D T1 Isotropic SAGITTAL	Head/Neck	GR	13	4.8	192	1.2	1.2
3D T2 Isotropic SAGITTAL	Head/Neck	SE	3200	380	192	1.2	1.2
*Exact values of TR and TI were adjusted manually, depending on decedent temperature							

Six decedents were subsequently excluded due to image quality issues. All image data were transferred to a PACS (Philips Intellispace, Version 4.5) for storage and viewing. Radiology Interpretation: PMCT interpretation was performed by a general radiologist with previous post-mortem and clinical imaging experience. Head and neck MRI interpretation was performed by a clinical neuroradiologist, experienced in emergency radiology. Both radiologists had access to basic demographic information (decedent age and sex), and were free to review the docket comments, which summarize the information provided by the scene investigator regarding the history and circumstances of the case (the same information that OMI forensic pathologists have when initially reviewing imaging prior to external examination or autopsy.) The radiologist interpreting PMCT was blinded to the PMMRI, and the radiologist reviewing PMMRI was blinded to the PMCT. Both radiologists were blinded to the pathologist's findings. Consensus: For each case, the imaging findings (injuries, pathologic conditions, or other observations) were entered into a spreadsheet by the study PI with a column for PMCT findings and a column for PMMRI findings, with tentatively matching findings entered in the same row. Imaging features described as "normal" in the radiology reports were not included. Each set of observations was reviewed by a consensus team consisting of a forensic pathologist and a clinical radiologist, neither of whom had previous knowledge of the case, and a data recorder (the study PI). The consensus team reviewed the decedent age and sex, and the docket comments, prior to reviewing the list of findings, but not the images or the autopsy report. The consensus team determined whether each observation was a "match" (i.e., the same finding appeared in the radiology report from

both modalities), and they further rated the significance of the finding, using a modified Goldman classification scheme:

Significance Rating	Definition:	Examples:
1	Fatal or potentially fatal injury or pathology	skull fracture with avulsion of brain matter; intracranial hemorrhage or infarction; AO dislocation; transection of spinal cord
2	Finding that is not itself likely to be fatal, but may be related to the cause of death, mechanism of death, or manner of death	nasal bone fracture; scalp hematoma; spinous process fracture
3	Finding that is unlikely fatal or related to the cause of death but is important for other reasons (e.g., public health, the decedent's family medical history)	cerebral cavernous malformation; healed fracture in case of suspected abuse; evidence of neurodegenerative disease*
4	Finding unlikely to be related to death and not important	deviated septum; mild cerebral volume loss in an elderly subject
n/a	Normal post-mortem changes and image artifacts (not indicative of injury of pathology)	loss of flow voids due to lack of blood flow, susceptibility artifact due to venous stasis, gas (if uniformly distributed) due to decomposition, susceptibility or streak artifact** due to dental restoration or medical device
*neurodegenerative disease could be a 2 depending on circumstances, e.g., if someone is found outside and appears to have died of exposure, then dementia may be contributory to death, vs. someone who dies as a passenger in an automobile accident, where neurodegenerative disease would be of potential interest to the family but not related to the cause of death		
**metal artifact could also be a 2 if caused by a foreign body		

Results: Subjects: A total of 94 decedents received both PMCT and PMMRI and were included in the study. These decedents subsequently received an external examination, and some decedents additionally received ancillary testing (e.g., toxicology) and/or a full autopsy. The 94 subjects included 56 males (ages 14 – 94 years, average 57 years) and 38 females (ages 19 – 95 years, average 59 years). In 24 cases, the decedent had a history of falls or seizures. According to the case pathologists' reports, 39 of the 94 decedents had evidence of traumatic injuries at external and/or internal examination: 13 cases of fatal trauma (including 9 cases with fatal head trauma), 4 cases with only moderate trauma (not contributing to death), and 22 cases with only minor trauma. The manners of death were 46 natural deaths, 42 accidents, 4 suicides, and 2 undetermined. The most common causes of death were 28 cases of cardiovascular disease, 26 cases of fatal intoxication, 13 cases of blunt trauma, and 7 cases of chronic ethanol abuse. Other causes of death were other

natural diseases (e.g., cancer, COPD, diabetes, etc.) accounting for 15 cases, 1 hanging, 1 drowning, 1 case of mechanical asphyxia, and 2 cases with an undetermined cause of death.

Imaging findings: For these 94 cases, the radiologists reported a total of 857 observations of injury, pathology, medical intervention, or post-mortem change in the head and neck (including the face). There were 475 observations from PMCT and 382 observations from PMMRI. These 857 observations resulted in 199 pairs of matched observations (same observation reported from both modalities), and 459 unmatched observations. Of the 199 pairs, 104 pairs were classified as non-findings (e.g., normal post-mortem changes, not an injury or pathology), and 95 pairs were considered matched findings. Of the 459 unmatched observations, 236 were classified as non-findings and 327 were considered findings. The vast majority of observations rated as a non-finding were the loss of gray-white differentiation reported at PMCT, diffuse restricted diffusion reported at PMMRI, or loss of vascular flow voids at PMMRI, all of which are expected normal post-mortem changes arising immediately after death. Other examples of non-findings are decompressed globes (also a normal PM change) and properly placed medical intervention. After eliminating non-findings, there were a total of 422 unique findings reported from PMCT and PMMRI of the head and neck, 95 of which were observed at both PMCT and PMMRI, 264 of which were observed at PMCT only, and 63 of which were observed at PMMRI only. The table below breaks down the number of findings by significance and modality. The numbers in parentheses in the top row are the total number of findings at each significance level, while rows 2 and 3 give the number and percentage of findings at each significance level for each modality.

Significance (# of findings)	**1** (64)	**2** (193)	**3** (39)	**4** (126)
PMCT	46 (72%)	156 (81%)	31 (79%)	126 (100%)
PMMRI	50 (78%)	95 (49%)	10 (26%)	3 (2%)

Although PMCT detected more total findings, PMMRI detected a greater number of fatal findings (significance Level 1). PMCT detected many non-fatal findings – findings which were either related to the cause of death (Level 2), not related to the cause of death but potentially important for other reasons (Level 3), or unimportant (Level 4). The next table shows the number of matched findings and unmatched findings, by modality:

Significance	Matched Findings	Unmatched Findings	Observed at PMCT only	Observed at PMMRI only
1	32	32	14	18
2	58	135	98	37
3	2	37	29	8
4	3	123	123	0
Total:	95	327	264	63

The 32 Level 1 findings observed at both PMCT and PMMRI included brain hemorrhages or infarction (most commonly), encephalomalacia/gliosis, mid-line shift, skull fracture, spinal cord compression, and cervical spine fracture or dislocation. There were 14 Level 1 findings appreciated at PMCT but not PMMRI, most commonly intraventricular hemorrhage. The 18 Level 1 findings seen at PMMRI but not PMCT (in 13 cases) were most commonly hemorrhages, infarcts, or encephalopathy characterized as "small" or "diffuse," findings expected to be below the sensitivity of PMCT. The majority of Level 1 PMMRI findings supported and reinforced both the PMCT findings and the pathologist's opinion. In two cases where PMMRI reported cerebral infarcts, the cause of death (fatal intoxication) may have been refined but would likely not have changed. Only one Level 1 finding (epidural hematoma and cord compression at C2) would likely change the primary cause of an accidental death, from fatal intoxication to blunt force injury.

Summary and Conclusions: While the complementarity of Autopsy and PMCT has been well-documented, this study suggests that PMCT and PMMRI are also complementary. The data show that the addition of PMMRI resulted in a 40% increase in the number of fatal (Level 1) findings in the head and neck (46 detected by PMCT; 64 detected by PMCT+PMMRI) in a cohort of 94 medical examiner cases with possible head or neck trauma. In one case, a new Level 1 finding reported at PMMRI would likely have changed the cause of death. Thus, in cases of high legal or public health importance, PMMRI should be considered. Our results also suggest that PMCT is a sufficient imaging modality in most medicolegal death investigations and is the preferred modality for detecting a variety of non-fatal findings, which may be related to the cause of death or are important to the medicolegal investigation, public health, or the decedent's family.