Sensitivity and Specificity of Postmortem CT for Detection of Thoracic Injury

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Abstract

Objective: Postmortem CT (PMCT) can help conventional autopsy in determining the cause of death and finding injury to various organs. Since injuries among several vital organs in the thorax can cause death, this research aims to assess the performance of PMCT in detecting injuries of the thoracic cavity organs.

Materials and Method: A total of 56 dead bodies by unnatural traumatic death who underwent PMCT before autopsy were collected. Thoracic traumatic findingsfrom PMCT were compared with data obtained from conventional autopsy wherethe autopsy was the reference standard and calculated for sensitivity, specificity, PPV, NPV, and accuracy.

Results: Findings in which PMCT showed high sensitivity included air (100%) and fluid (86.67%). Interms of bone fracture, sensitivity and accuracy were79.18% and 88.69%, respectively, especially for T-spine fractures (sensitivity 92.31%, accuracy 87.50%) and clavicle fractures (sensitivity 90%, accuracy 89.29%). For rib fractures, PMCTexhibited moderate to high sensitivity (68.18-91.67%) and high accuracy (78.57-98.21%). For soft tissueinjuries, PMCT had high specificity (99.21%), but low sensitivity (34.94%).

Conclusion: PMCT is useful in detecting thoracic injuries in conjunction with the conventional autopsy by helping to diagnose bone fractures, abnormal air, and fluid with high sensitivity and specificity.

Keywords: *Postmortem CT;Virtual autopsy; Chest injury; Trauma;Forensic Imaging; Forensic Pathology.*

Introduction

Imagingis useful for diagnosing pathologies in the body, making it useful in postmortem inquest.This is especially true for postmortem CT(PMCT),which plays a role in enhancing conventional autopsy to determine the cause of death[1–9], detect organ injury, and some internal organ pathologies. The conventional autopsy had limited access to some internal injuries[10–12]such as facial bone fractures[7,13], spinal fractures[7,9,13,14],etc, and had limitations in its methods to detectpathologies caused by abnormal air, such as pneumothorax and air embolism[15–18]. Air generated within the body after death is something that is difficult to prove with conventional autopsy and requires additional techniques. In our experience,there were cases where this could not be proven, or if it was present in small quantities, may not have been possible to verify[19]. With these types of injuries, PMCT can be helpful for detection and in the detection of multiple injuries[3,10,18,20,21].

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The thoracic region contains many vital organs, such as the heart, lungs, aorta, etc. Injury to the thoracic organs can be a common cause of death. For example, tension pneumothorax had a death rate of 40%[22], flail chest had a death rate of 18%[23], andcardiac tamponade[24]can come from injury to the heart or the aorta. These are all possible causes of death. Injury to the chest is the fourth most common cause of deathwith a death rate of18.7%[25].

PMCTis effective in detecting trauma to the pleura, thoracic bony structures,with high sensitivity and specificity of 100%[7,26] but it has a lowersensitivity of50-94% and specificity of 85-94% for soft tissue injuries[26]. It could be seen that thoracic PMCT showed differences in performance between bone, soft tissue, fluid, and air. In addition, the researcher observed that there were several times when the autopsy revealed injuries that did not match the PMCT results. The researcher, therefore,would like to study the sensitivity and specificity of PMCT in the detection of thoracic injuries.

Material and Methods

Sample

The sample was comprised of unnaturally dead bodies that were fully autopsied between 2012 and 2020 and underwent PMCT before the autopsy. The exclusion criteria werethe dead bodies withouta history of injury prior to death,or withsigns of decomposition on external examination.

Data Collection

Data collected were gender, age, incident history, cause of death, circumstances of death, and the time period from deceased to autopsy (postmortem interval: PMI). The cause of death was divided into6 groups:1) head injury,2) neck injury,3) chest injury,4) abdominal injury,5) multiple injuries (when more than one fatal injury group was involved) and,6) others.

Postmortem CT

PMCT was performed on a 128-slice Aquilion CX scanner (Toshiba Medical Systems Corporation, Tokyo, Japan) or a GE revolution HD (GE Healthcare, Chicago, IL, USA). Scan parameters were as follows: slice thickness 2.0-2.5 mm, rotation time 0.5-0.6 s, tube voltage 120-140kVp, and tube current 200-300mAs without IV contrast. The examination was performed from the head to the halfway point of the upper leg or below, depending on the height of the body. Images were collected for analysis in the Picture Archiving and Communication Systems (PACS) and results were formally reported in the reporting system. The images were interpreted by emergency radiologists who had some experiences in postmortem imaging. The radiologists who interpretedthe images knewthe trauma history of the corpses but did not know the results of the autopsy.

Conventional autopsy

The autopsy was performed by forensic pathologists who were aware of the PMCT results using standard methods. The body was dissected throughout the body with the removal of all internal organs, including the brain, heart, lungs, liver, pancreas, spleen, kidneys, adrenal glands, and uterus (in the case of female corpses) for a thorough examination.The cause of death was recorded in the report.

Definitions

The definitions of each type of injury were described below.

1. Bone injuries included rib fracture, sternum fracture, clavicle fracture, and thoracic spine fracture. Rib fractures were described according to each rib separately,as 1st-12thribs, right and left. The scapular fracture was not included in this study because of technical limitation of the conventional autopsy.

2. Pleura injury included hemothorax or pneumothorax.

3. Lung injury included lung contusion or lung laceration.

4. Heart injury included heart contusion or heart

laceration.

5. Aorta injury includedaortic tear or periaortic hemorrhage.

6. Superior vena cava (SVC) and inferior vena cava (IVC) injuries included hemorrhage or tear of the SVC or IVC.

7. Diaphragm injury included diaphragm contusion, diaphragm laceration, or traumatic diaphragmatic hernia.

8. Thoracic spinal cord injury included spinal cord hemorrhage(epidural hemorrhage or subdural hemorrhage), spinal cord contusion, or spinal cord laceration.

The definitions of the injury groupsare divided into four groups of injuries:

1. Bone injury: rib fracture, sternum fracture,clavicle fracture, and T-spine fracture.

2. Soft tissue and organ injury: heart, lung, diaphragm, and thoracic spinal cord injuries.

3. Fluid: hemothorax.

4. Air: pneumothorax.

Statistical Analysis

Injury data of chest organs and parts from conventional autopsy and PMCT were compared and calculated to determine sensitivity, specificity, PPV, NPV, and accuracy using conventional autopsy as the reference standard.

Results

Data were collected from 2012 - 2020for corpses that were PMCT tested. From a total of 63 cases, 7 cases were non-trauma and were excluded. Thus, a total of 56 cases were included in the study, 47 were men and9 were women, ranging from15-81 years of age, with a median age of 33 years. There was one case with no age identified. For the cause of death, the manner of death, and the postmortem interval(PMI), the dataare shown in Table 1.

Table 1: Cause of death, manner of death, and postmortem interval of the included cases.

Details		Number (N = 56)
Gender	Male	47
	Female	9
Age*	11-20 y	6
	21-30 y	17
	31-40 y	12
	41-50 y	9
	51-60 y	5
	61-70 y	3
	71-80 y	2
	>80 y	1

Cont... **Table 1: Cause of death, manner of death, and postmortem interval of the included cases.**

Cause of death	Head injury	27
	Neck injury	3
	Chest injury	14
	Abdominal injury	2
	Multiple injuries	9
	Natural**	1
Manner of death	Homicide	9
	Suicide	3
	Accident	38
	Natural**	1
	Undetermined	5
Postmortem interval	0 – 6 hours	9
	6 – 12 hours	18
	12 – 18 hours	12
	18 – 24 hours	13
	> 24 hours	4

* one case of unknown age

** History of trauma before death but the cause of death was myocardial infarction.

The results of PMCT compared to conventional autopsy are shown in Table 2, comparing the number of findings.

Table 2: Comparison of thoracic injuries detectedwith PMCT and autopsy (n=56)

Injury	**PMCT + Autopsy +**	**PMCT – Autopsy -**	**PMCT + Autopsy -**	**PMCT - Autopsy +**
Sternum fracture	8	38	7	3
Rib fracture*	298	898	67	81
Clavicle fracture	9	41	5	1
T-spine fracture	12	37	6	1
Pneumothorax	5	23	28	0
Hemothorax	26	20	6	4
Lung injuries	24	15	1	16

Cont... **Table 2: Comparison of thoracic injuries detectedwith PMCT and autopsy (n=56)**

Lung contusion	16	21	1	18
Lung laceration	17	27	3	9
Heart injuries	0	29	0	27
Heart contusion	0	36	0	20
Heart laceration	0	46	0	10
Aorta injury	0	49	1	6
SVC, IVC injury	0	56	0	0
Diaphragm injury	4	51	0	1
Spinal cord injury	1	51	0	4

*Rib fractures were counted from each rib

The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of PMCT when the conventional autopsy was the reference standard, are shown in Table 3. For heart injury and aorta injury, values could not be calculated except for the negative predictive value, because either the PMCT results were all negative or the number of pathologies was very low.

Table 3: Sensitivity, specificity, PPV, NPV, and accuracy of PMCT in the detection of organ injury

Injury	Sensitivity	Specificity	PPV	NPV	Accuracy
Sternum fracture	72.73%	84.44%	53.33%	92.68%	87.50%
Rib fracture	78.63%	93.06%	81.64%	91.73%	88.99%
Clavicle fracture	90.00%	89.13%	64.29%	97.62%	89.29%
T-spine fracture	92.31%	86.05%	66.67%	97.37%	87.50%
Hemothorax	86.67%	76.92%	81.25%	83.33%	82.14%
Lung injury	60.00%	93.75%	96.00%	48.39%	69.64%
Lung contusion	47.06%	95.45%	94.12%	53.85%	66.07%
Lung laceration	65.38%	90.00%	85.00%	75.00%	78.57%
Heart injury	NA	NA	NA	51.79%	NA
Heart contusion	NA	NA	NA	64.29%	NA
Heart laceration	NA	NA	NA	82.14%	NA
Aorta injury	NA	NA	NA	89.09%	NA
Diaphragm injury	80.00%	100.00%	100.00%	98.08%	98.21%
Thoracic cord injury	20.00%	100.00%	100.00%	92.73%	92.86%

For main venous injuries (SVC, IVC injury), PMCT results and autopsy were all negative, so values could not be calculated. The conventional autopsy could not detect pneumothoraxin some cases and therefore could not be used as a reference standard.

Thoracic injuries with the highest sensitivity of PMCT were T-spine fractures (92.31%), followed by clavicle fractures (90%), and hemothorax (86.67%). The injuries with the highest specificity included diaphragm injury and thoracic cord injury (100%), followed by lung contusion (95.45%), though the latter two had low sensitivity of 20-47%.

Detecting rib fractureswith PMCT resulted inan overallsensitivity of 78.63% and specificity of 93.06%. Sensitivity ranged from 63.64% to 91.67%, with the highest sensitivity being recorded at the right 10th rib, left 9th rib, left 10th rib, and left 12th rib, respectively. Specificity ranged from 85.29% to 100%, with the highest being atthe left 12th rib, left 10th rib, and right 8th rib, respectively. PPV ranged from 55.56% to 100%, with the maximum found at the left 12th rib, right 4th rib, right 3rd rib, respectively. NPV ranged from 79.49% to 97.87%, with the highest being the left 12th rib, left 10th rib, right 12th rib, and left 9th rib, respectively. Accuracy ranged from 80.36% to 98.21%, with the highest being the left 12th rib, left 10th rib, right 8th rib, and right 10th rib, respectively. The details were shown in Table 4.

Table 4Sensitivity, specificity, PPV, NPV, and accuracy of PMCT in the detection of rib fracture

Injury	Sensitivity	Specificity	PPV	NPV	Accuracy
left 1st rib	78.95%	94.59%	88.24%	89.74%	89.29%
left 2nd rib	71.43%	88.57%	78.95%	83.78%	82.14%
left 3rd rib	63.64%	91.18%	82.35%	79.49%	80.36%
left 4th rib	75.00%	87.50%	81.82%	82.35%	82.14%
left 5th rib	68.18%	85.29%	75.00%	80.56%	78.57%
left 6th rib	73.68%	91.89%	82.35%	87.18%	85.71%
left 7th rib	75.00%	90.00%	75.00%	90.00%	85.71%
left 8th rib	80.00%	90.24%	75.00%	92.50%	87.50%
left 9th rib	90.00%	93.48%	75.00%	97.73%	92.86%
left 10th rib	90.00%	97.83%	90.00%	97.83%	96.43%
left 11th rib	81.82%	95.56%	81.82%	95.56%	92.86%
left 12th rib	90.00%	100.00%	100.00%	97.87%	98.21%
right 1st rib	76.47%	87.18%	72.22%	89.47%	83.93%
right 2nd rib	75.00%	94.44%	88.24%	87.18%	87.50%
right 3rd rib	75.00%	97.22%	93.75%	87.50%	89.29%
right 4th rib	85.00%	97.22%	94.44%	92.11%	92.86%
right 5th rib	78.95%	91.89%	83.33%	89.47%	87.50%
right 6th rib	86.67%	92.68%	81.25%	95.00%	91.07%
right 7th rib	86.67%	92.68%	81.25%	95.00%	91.07%
right 8th rib	85.71%	97.62%	92.31%	95.35%	94.64%
right 9th rib	84.62%	93.02%	78.57%	95.24%	91.07%
right 10th rib	91.67%	95.45%	84.62%	97.67%	94.64%
right 11th rib	71.43%	91.84%	55.56%	95.74%	89.29%
right 12th rib	87.50%	91.67%	63.64%	97.78%	91.07%

When the trauma pathology was grouped into four groups to calculate the diagnostic performance of PMCT compared to conventional autopsy (Table 5), PMCT was found to have relatively high accuracy (78.13% - 88.69%), with the highest value indicatedfor bone injuries. For abnormal air detection, PMCT had the highest sensitivity,detecting NPV at 100%, but its specificity, PPV, and accuracy could not be determined because it could not be detected in conventional autopsy in many cases due to the technical limitations.

Table 5Sensitivity, specificity, PPV, NPV, and accuracy of PMCT in the detection of a group of injuries

Group of Injury	Sensitivity	Specificity	PPV	NPV	Accuracy
Bone	79.18%	92.27%	79.37%	92.18%	88.69%
Soft tissue and Organ	34.94%	99.21%	93.55%	82.30%	83.33%
Fluid	86.67%	76.92%	81.25%	83.33%	82.14%
Air	100.00%	NA	NA	100.00%	NA

Discussion

This research shows that PMCT is highly accurate for the diagnosis of fluid and air, as well as injuries tosoft tissue and organs in the thoracic cavity, with the highest sensitivity for pneumothorax diagnosis and the highest accuracy for bone fractures (especially T-spine fracture and clavicle fracture). It is also superior to conventional autopsy in the diagnosis of pneumothorax.

Bone fracture

This research is consistent with previous research findings proclaiming PMCT to be very accurate for bone injuries, with accuracy levels up to 88.69%. Clavicle fracturedisplays the highest accuracy of 89.29%, as shown in research by Moskala A. et al.[27], where PMCT can detect clavicle injuries better than any other bones in the thorax. Overall sensitivity, specificity, and accuracy in this study were lower than that found bySifaoui I. et al.[26], who showed the sensitivity of 100% and specificity of 100%, but similar to a study byAmpanozi G. et al.[28], which had a sensitivity of 86%.

For rib fractures, PMCT was found to have a sensitivity of 78.63% and specificity of 93.06%. Research by Schulze C. et al.[29]obtained lower sensitivity rates, but slightly higher specificity. In the area of rib fractures, some differences from past research were found. In research by Hamanaka K. et al.[30], it was shown that PMCT detected fractures of the 2nd, 5th and6th ribs very well. As for the Schulze C. et al.[29]research, PMCT presented better detection at the 1st rib. In this research, the rib fracture siteswhere PMCT showed the highest accuracy were the left 10th rib, left 12th rib, right 8th rib, and right 10th rib,which arefalse ribs, as well as floating ribs.

As for scapular fractures, it was found that PMCT revealed a certain number of positive results, whereas conventional autopsy could not reach the scapula during the examinationin many cases because of technical limitation.Therefore, we did not include the scapular fracture in this study.

Soft tissue and organ injury

For injuries to soft tissue and organs, PMCT exhibited high specificity (99.21%), comparable withAghayev E. et al.[31], but showed lowersensitivity(34.94%)than the study of Ampanozi G. et al.(65%)[28].

In lung injuries, PMCT was higher in specificity than Aghayev E. et al.[31] for both lung contusion and lung lacerations. Diaphragm injury was the best soft tissue and organ injury to be detected by PMCT, withasensitivity of 80%,a specificity of 100%, and an accuracy of 98.21%. Thisis similar to research by Sifaoui I. et al.[26] with 94% sensitivity, 94% specificity, and 97% accuracy. Three-quarters of the four true positive cases were detected for diaphragmatic herniation. These values were higher than those found in research by Aghayev E. et al.[31] (sensitivity 50% and specificity 100%),and that of Christe A. et al.[32] (sensitivity 0% and specificity 94%).

Pneumothorax

Pneumothorax was the most common condition, presenting in 28 out of 56 cases (50%) in PMCT images, but not in the conventional autopsy. Only 5 cases were found in both conventional autopsy and PMCT. No cases were found only in the autopsy but not by PMCT. This is consistent with other studies, as well, showing that PMCT was able to detect pneumothorax[3,31,33]. This is the unique property of PMCT allowing abnormal air collection to be detected even in small amounts,whilea conventional autopsy is not able to confirm pneumothorax in those cases.

Hemothorax

In this study, PMCT had a sensitivity of 86.67% in the diagnosis of hemothorax, which was 76% higher than that of the research of Ampanozi G. et al.[28]

Table 6: Comparisonof sensitivity and specificity with previous studies

Finding	This research	Ampanozi G et al. (2020)28	Sifaoui I et al. (2017)26	Schulze C et al. (2013)29	Christe A et al. (2009)32	Aghayev E et al. (2008)31*
Bone fracture	Sen 79.18% Spec 92.27%	Sen 86%	Sen 100% Spec 100%	-	-	-
Rib fracture	Sen 78.63% Spec 93.06%	-	-	Sen 63% Spec 97%	-	-
Soft tissue & organ	Sen 34.94% Spec 99.21%	Sen 65%	-	-	-	-
Lung injury	Sen 60% Spec 93.75%	-	Sen 97.5% Spec 85%	-	-	-
Lung contusion	Sen 47.06% Spec 94.45%	-	-	-	-	Sen 95-100% Spec 60%
Lung laceration	Sen 65.38% Spec 90%	-	-	-	-	Sen 90-100% Spec 57-70%
Diaphragm injury	Sen 80% Spec 100%	-	Sen 94% Spec 100%	-	Sen 0% Spec 94%	Sen 50% Spec 60-100%
Fluid (hemothorax)	Sen 86.67% Spec 76.92%	Sen 76%	-	-	-	Sen 100% Spec 50-75%
Air (pneumothorax)	Sen 100%	-	-	-	-	Sen 100% Spec 50%

* Calculated from data provided within thearticle

Limitations

The limitations of this research are its retrospective nature with a relatively small number of cases, and some of the findings were infrequent that the statistical values could not be calculated. Our results were obtained from PMCT results without re-reviewing images. Although this reflects a real clinical practice it does not allow an evaluation of the most optimal performance of PMCT. The study period was quite long and may influence the experience of the radiologists who interpreted the results. The PMCT technique did not use a contrast agent injection, making it limited in the diagnosis of vascular injury. The conventional autopsy had limitations, as well, as some areas were inaccessible, difficult to reach, or some techniques were difficult to perform, making it impossible to use as a reference standard for certain pathologies.

Conclusion

PMCT is highly accurate in the diagnosis of bone fractures, abnormal fluid, and air in the thoracic cavity, and can be used as a complement to autopsy, particularly in the diagnosis of pneumothorax and some fractures. This test has a high specificity for diaphragm injury, but is not very good on other soft tissue injuries.

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