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Abstract The aim of this study was to assess the role of postmortem computed tomography (PMCT) as an alternative for autopsy in determining the cause of death and the identification of specific injuries in trauma victims. A systematic review was performed by searching the EMBASE and MEDLINE databases. Articles were eligible if they reported both PMCT as well as autopsy findings and included more than one trauma victim. Two reviewers independently assessed the eligibility and quality of the articles. The outcomes were described in terms of the percentage agreement on causes of death and amount of injuries detected. The data extraction and analysis were performed together. Fifteen studies were included describing 244 victims. The median sample size was 13 (range 5–52). The percentage agreement on the cause of death between PMCT and autopsy varied between 46 and 100%. The overall amount of injuries detected on

CT ranged from 53 to 100% compared with autopsy. Several studies suggested that PMCT was capable of identifying injuries not detected during normal autopsy. This systematic review provides inconsistent evidence as to whether PMCT is a reliable alternative for autopsy in trauma victims. PMCT has promising features in postmortem examination suggesting PMCT is a good alternative for a refused autopsy or a good adjunct to autopsy because it detects extra injuries overseen during autopsies. To examine the value of PMCT in trauma victims there is a need for well-designed and larger prospective studies.

Keywords Review · Postmortem · CT · Autopsy · Trauma

Abbreviations CT: computed tomography · PMCT: postmortem computed tomography · MRI: magnetic resonance imaging

Introduction

Trauma is one of the leading causes of death [1]. Injuries cause 5 million deaths every year worldwide, which accounts for 9% of global mortality. The numbers for morbidity are even higher and injury accounts for 16% of the global burden of disease [2]. Since the 1980s trauma mortality has been described in epidemiology studies [3–11]. All of these studies contain valuable information for prevention purposes but also serve as a feedback tool for possible improvements in trauma assessment.

Autopsy is considered the reference standard for postmortem evaluation regarding the detection of the causes of death and sustained (traumatic) injuries. In most cases, autopsy results can explain the cause of death, the number of injuries sustained, and the trauma mechanism in trauma victims. Furthermore clinical autopsies are performed to evaluate potential missed injuries after unsuccessful trauma resuscitation. In most countries, clinical autopsies are performed with permission from the family of the deceased. As a consequence of its invasiveness, permission to conduct a clinical autopsy is often not given. Unlike clinical autopsies,

forensic (or medicolegal) autopsies may be ordered by the legal authority, which has the sole power to order this type of autopsy. Even though this examination often might seem medically desired, it is not always indicated for medicolegal purposes and is therefore frequently omitted.

In addition, autopsies are very time consuming and labor intensive. The current declining number of autopsies [12–15] could mean that valuable data regarding the actual traumatic injuries and causes of death will be either hard to obtain, misclassified, or even lost [16, 17]. To circumvent this problem several institutes are studying the value of postmortem computed tomography (PMCT) in continuation with or without magnetic resonance imaging (MRI) [18–20]. Recently, there have been great improvements in the quality and multiplanar reformatting of CT imaging. Since this radiological technique is noninvasive and an accepted imaging technique its use could be an alternative for clinical autopsy.

The aim of this review was to investigate the value of PMCT as a reliable substitute for autopsy in trauma victims for revealing the cause of death and diagnosing specific injuries.

Material and methods

A systematic search of the literature was conducted to identify studies examining the value of postmortem computed tomography (PMCT) as an alternative for autopsy to diagnose the cause of death and specific injury in trauma victims.

Criteria for inclusion

Eligible articles were selected if: (1) the index test(s) included a PMCT, (2) the reference standard(s) included autopsy, (3) the aim of the selected studies was to determine the cause of death and/or major injury, and (4) the included patients were trauma victims. Trauma was defined as a physical injury or wound caused by an external force which may cause death or permanent disability.

Search strategy

The MEDLINE and EMBASE database were searched with the following free text and MeSH search terms: (autopsy OR necropsy OR obduction OR abduction OR postmortem OR forensic investigation) AND (computed tomography OR CAT scan OR MSCT OR CT) AND (trauma). There was no language, age, or publication year restriction, and articles were included if they evaluated two or more trauma victims.

Additionally, the reference list of each eligible article was screened for other relevant publications (cross-

reference search) to identify additional studies not found in the computerized search (MS). Furthermore, a manual search of the following journals was performed (MS) that reported most frequently about the topic of interest: *Forensic Science International*; *Forensic Science, Medicine, and Pathology*; *Rechtsmedizin*; *The American Journal of Forensic Medicine and Pathology*; *International Journal of Legal Medicine*; *Journal of Forensic and Legal Medicine*; *Journal of Clinical Forensic Medicine*; *Legal Medicine (Tokyo)*; *Journal of Trauma*; *Injury*; *RöFo*; and *Radiology*.

Meeting abstracts, unpublished data, and theses were not included in our search.

The last search was performed in May 2008.

Selection of dedicated studies

Two reviewers (MS & TPS) performed the literature search together. Both reviewers (MS & TPS) independently assessed the titles of the literature search to determine whether they were potentially relevant. Abstracts of the potentially relevant titles were retrieved. After that, both reviewers assessed the abstracts of the selected titles and retrieved the full text articles of potentially relevant abstracts. Again if there was any doubt if an abstract should be included or the abstract was absent, the full text of the article was retrieved. The final step of inclusion was always based on the full text article. In case of a disagreement the third reviewer (PHPFKJ) was consulted. During the selection process no concealment of authors/institutions was used.

Assessment of study quality

Two reviewers (MS & TPS) independently assessed the quality of the selected studies. We used an adapted version of the QUADAS tool as our quality assessment tool [21]. The QUADAS tool is a validated, generic tool for the assessment of quality in diagnostic accuracy studies. It consists of individual items addressing potential sources of bias and variation in accuracy studies. We selected all relevant items and added additional items specific for this review. Two reviewers independently assessed methodological quality, and, in case of a disagreement, a third reviewer (PHPFKJ) was consulted.

For quality assessment we have analyzed the overall description of the study methods and the final and/or intermediate results reported (i.e., inclusion parameters, study population, the technique of CT employed and autopsies performed, the time period between the examinations, blinding of the examinations, etc.). Studies were considered poor quality and were excluded if they had a lack of information on inclusion criteria, PMCT and/or autopsy description, and had no evidence of blinding.

Data extraction

Data were extracted by the two reviewers (MS & TPS). Because of the complexity of the data, this was performed together. Furthermore, every corresponding author was contacted if the reported data were unclear or incomplete.

Statistical analysis

The main analysis focused on the proportion of patients in which the cause of death determined by postmortem CT was in agreement with the cause of death established during autopsy (the reference standard). For each study, we calculated this percentage agreement together with the 95% confidence interval based on the method of Wilson [22]. These individual estimates were then plotted together in a forest plot to give a visual impression of the amount of heterogeneity. A random effects pooling was performed using the logit transformed proportion of agreement as outcome variable, while using the exact binomial distribution to account for differences in precision in estimated proportions across studies. The random effects pooling was performed in SAS using the nonlinear mixed model procedure (SAS version 9.1, SAS Institute Inc., Cary, NC, USA). The I^2 value was calculated as a measure of inconsistency, where the I^2 describes the percentage of total variation across the studies that is due to heterogeneity rather than chance [23]. Similar analyses were done for the percentage agreement between CT and autopsy for specific types of injuries. Again the findings during autopsy were considered as the correct ones (reference standard).

Results

Search strategy and selection

The computerized search resulted in 465 titles from the EMBASE database and 849 titles from the MEDLINE database (Fig. 1). After reviewing the titles and eliminating the duplicates from both databases 71 titles were selected for further evaluation. Based on the abstracts, 32 papers were excluded because they did not match the inclusion criteria resulting in 39 full text articles that were reviewed. Based on the full text 23 articles of the 39 (59%) were not eligible for quality assessment because they did not meet our inclusion criteria (Fig. 1). The manual search and cross-reference search resulted in three additional papers. In total 19 papers were eligible for quality assessment [24–42]. Within these 19 papers four articles were excluded: one because the descriptive data were not suitable for data extraction and the author could not be contacted, i.e., the data were merely descriptive and no numerical data could be obtained [40]; the other three studies were excluded because of poor quality [39, 41, 42]. The Cohen's kappa

coefficient for full text selection was 0.79 which can be considered to indicate substantial agreement [43].

All data were extracted from the remaining 15 studies (Table 1). All 15 studies were observational studies, 8 of them had retrospective data collection (53%) and 7 prospective (46%). Twelve studies provided data about the percentage agreement on the causes of death and seven studies reported specific data about the injuries per anatomical region.

The flowchart of the included studies is represented in Fig. 1 [44].

Data extraction

Data were extracted from all 15 studies [24–38]. We contacted the authors of 6 studies because data were insufficient or incomplete and received the requested data. The 15 studies included a total of 244 patients with a median sample size of 13 (range 5–52).

The period between the time of death and CT varied from 3 to 192 h, and the time between death and autopsy varies from 15 to 240 h. Standard autopsy implied dissection of the chest, abdomen, and pelvis with all internal organs being examined. Neuropathological examination implied an accurate dissection of the cranium and neck. Standard CT was performed with an MSCT system with which the skull was imaged to the pelvis, the distal femur or the toes with multiplanar reconstructions. However, the protocols for CT, when described, varied widely regarding the type of MSCT machines (2- to 16-slice CT systems). The slice thickness varied between 1.25 and 5 mm for the head and neck, and 1.25 and 10 mm for the torso. Furthermore, multiple variations were found in rotation and table speeds, strength of radiation used, and the usage of and methods for multiplanar reconstructions.

Table 2 shows the data of the twelve studies about trauma mechanisms and the percentage agreement on the causes of death found by PMCT and autopsy.

Figure 2 shows a forest plot of the 11 studies which had numerical data on the causes death found by PMCT and autopsy. Four studies had numerical data on specific injuries diagnosed with CT but not on the causes of death. These four studies were therefore omitted in Fig. 2. This plot also gives information about the heterogeneity of the data with an inconsistency I^2 of 76.4%.

Table 3 shows the results of the seven studies reporting data about the injuries detected by PMCT and autopsy. We have clustered the injuries per body region as described in the abbreviated injury scale (AIS) [45], while the injury of the face was added to the head/neck region. One of the reasons for using this classification is that different levels of injury severity can be clearly defined (e.g., from skin contusion to severe liver laceration). Another reason is that several trauma studies only report on injuries sustained in specific regions. For the face/head/neck region PMCT found

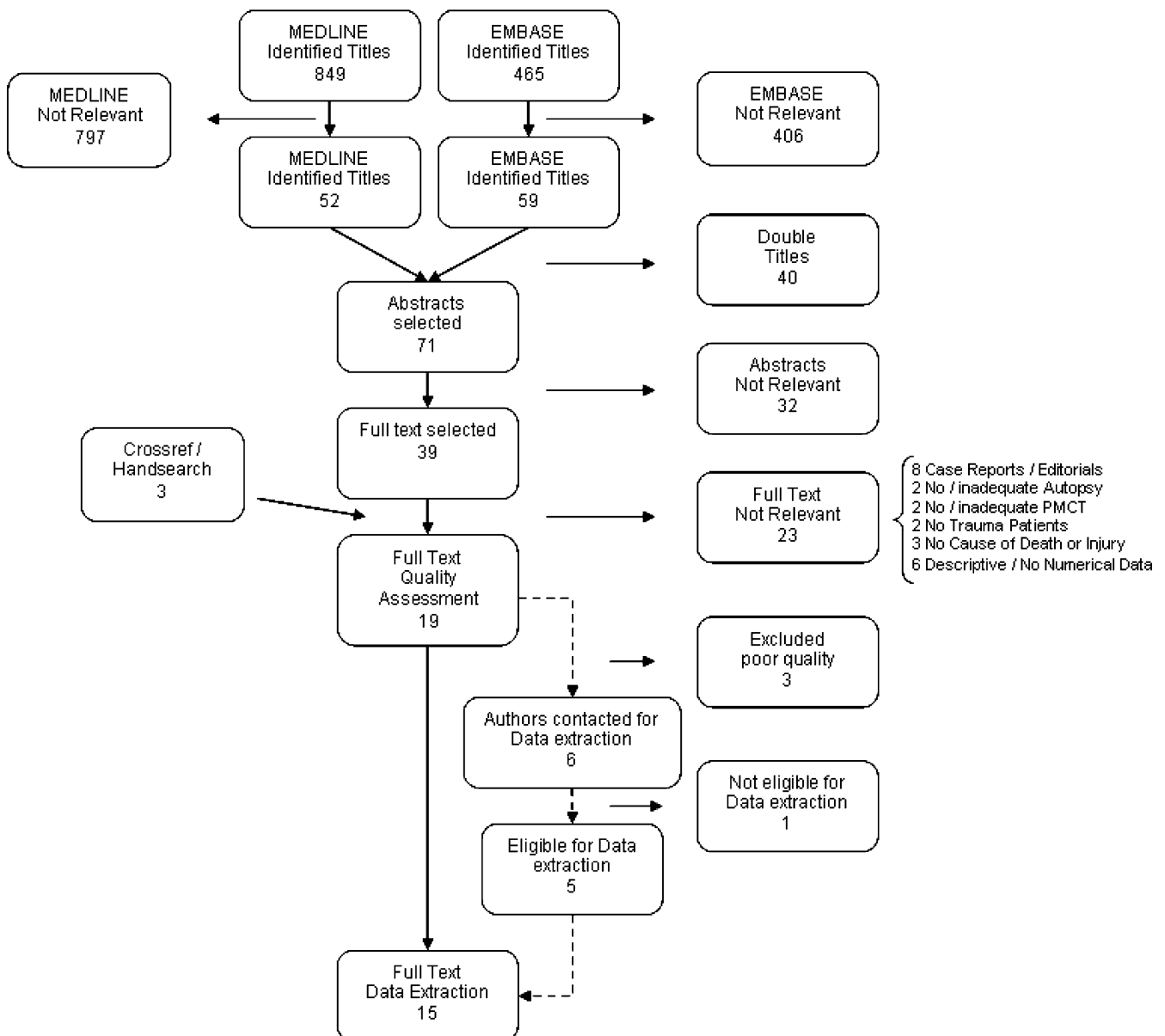


Fig. 1 QUOROM flowchart

between 53 and 100% of the injuries, and in particular the gunshot injuries were very accurate. The chest region had an even higher percentage of detected injuries (75–100%). Although the percentage of detected injuries of the abdomen is high, the absolute number of injuries found in this body region was limited, with Hoey et al. reporting the highest number, 10 for PMCT out of 13 injuries detected at autopsy [29]. One study is missing in Table 3 because the reference standard was a combination of the findings on autopsy and PMCT [32]. In this specific study, the PMCT detected 15% of the total number of injuries that were missed during autopsy. As a result the percentage agreement between PMCT and autopsy was not 100% but 85%.

Discussion

The percentage agreement on the cause of death found by PMCT and autopsy in this study ranged from 46 to 100%. For all the body-region-specific injuries the percentage agreement also varied considerably between 53 and 100%. Autopsies have been performed for centuries, whereas PMCT has been used as a postmortem examination method for no longer than a decade. The far greater experience with autopsies could explain some of the differences in reported percentage agreement between PMCT and autopsy. Because we expect that interpretation of PMCT is subject to a learning curve, the differences will probably decrease

Table 1 Study characteristics of the 15 eligible studies

First author and ref. no.	Country	Journal	Year	Language	Eligible trauma patients (n)
Thali [35]	Switzerland	<i>J. Forensic Sci.</i>	2003	English	33
Yen [38] ^a	Switzerland	<i>Forensic Sci. Int.</i>	2007	English	52
Paperno [33]	Germany	<i>RöFo</i>	2005	German	11
Levy [31]	USA	<i>Radiology</i>	2006	English	13
Hoey [29] ^a	Israel	<i>J. Trauma</i>	2007	English	12
Yen [36]	Switzerland	<i>J. Magn. Reson. Imaging</i>	2005	English	9
Yen [37] ^a	Switzerland	<i>Int. J. Legal Med.</i>	2005	English	5
Christe [26]	Switzerland	<i>Eur. Radiology</i>	2008	English	10
Harcke [28]	USA	<i>Am. J. Forensic Med. Pathol.</i>	2007	English	13
Levy [32]	Israel	<i>Isr. Med. Assoc. J.</i>	2007	English	6
Rutty [34]	UK	<i>J. Forensic Sci.</i>	2007	English	5
Donchin [27] ^a	Israel	<i>J. Trauma</i>	1994	English	13
Andematten [25]	Switzerland	<i>Leg. Med. (Tokyo)</i>	2008	English	22
Leth [30] ^a	Denmark	<i>Forensic Sci. Med. Pathol.</i>	2006	English	16
Aghayev [24] ^a	Switzerland	<i>J. Thorac Imaging</i>	2008	English	24

^aAuthor was contacted

when there is more research performed on and more experience with PMCT. Second, the diversity in the studies' CT protocols, population size, the experience level of imaging interpretation, subject population, and different institutional levels could account for the substantial heterogeneity in the reported percentages of agreement. One of the 15 studies described a study population of more than 40 patients, 4 studies included less than 10 patients, and the median population size was 13. In addition the CT techniques and the methods for multiplanar reconstructions were different for most studies.

However, according to all protocols the patients were at least examined from skull to the pelvis or for neuroimaging from skull to the first thoracic vertebral body.

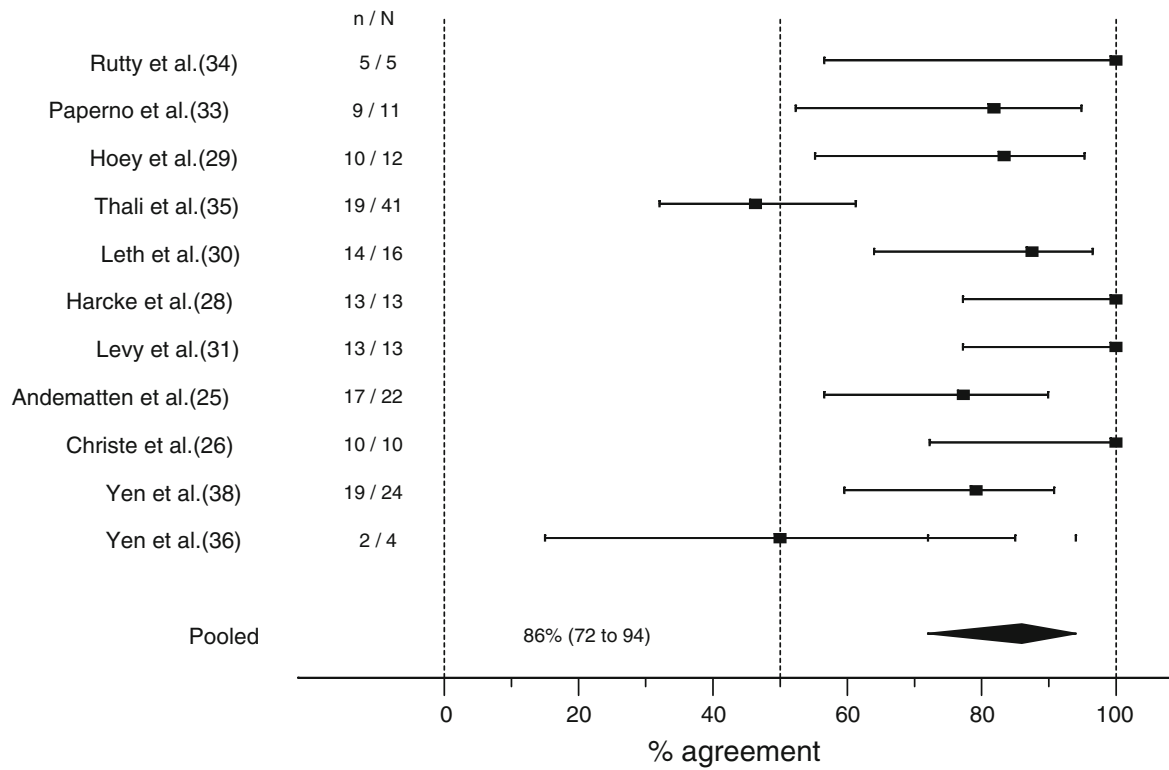
Furthermore, the level of injuries described as the cause of death varied from bleeding in the thoracic cavity to hemorrhagic shock from a ruptured thoracic aorta. One study even reported combined causes of death [35]. Therefore autopsy reported more causes of death than patients. Although this can be common in forensic and medical practice, it makes the method of data interpretation and testing more difficult and different from the other tests.

Table 2 Percentage agreement on causes of death

First author and ref. no.	Trauma mechanism	TP/TP + FN	Agreement on cause of death (%)
Rutty [34]	Various	5/5	100
Paperno [33]	Various	9/11	82
Hoey [29]	Various	10/12	83
Thali [35] ^a	Various	19/41	46
Leth [30]	Various	14/16	88
Harcke [28]	GSW	13/13	100
Levy [31]	GSW	13/13	100
Andematten [25]	GSW	17/22	77
Aghayev [24]	Blunt chest trauma	—/—	85
Christe [26]	Drowning	10/10	100
Yen [38]	Neurotrauma	19/24	79
Yen [36]	Head + neck trauma	2/4	50

GSW gunshot wounds, TP causes of death diagnosed with PMCT, FN causes of death diagnosed with autopsy and overseen on PMCT, Various mixed trauma mechanisms

^aMultiple causes of death per patient possible



n: causes of death diagnosed by CT
N: causes of death diagnosed by autopsy
% agreement: proportion of patients in which the cause of death determined by PMCT is in agreement with the cause of death established during autopsy

Fig. 2 Forest plot showing percentage agreement on causes of death

Overall, the combination of relatively small studies and substantial differences in design and study population led to substantial heterogeneity in reported percentage agreement (inconsistency $I^2 = 76.4\%$).

The studies included in this systematic review used autopsy as the reference standard and therefore all PMCT

findings that were not found during autopsy were considered false positive. More than half of the studies reported significant false positive findings with PMCT [24, 25, 27, 29, 31–33, 35, 38]. Some injuries like facial fractures, gas embolisms, small pneumothoraces, pneumopericardium, and pneumomediastinum are difficult to

Table 3 Identified injuries per anatomical region

Region	Levy et al. [31]	Andematten et al. [25]	Hoey et al. [29]	Aghayev et al. [24]	Yen et al. [36]	Donchin et al. [27]	Thali et al. [35]
Head/neck/face	100 (24/24)	100 (25/25)	100 (19/19)	n.a.	53 (28/53)	n.a.	n.a.
Chest	100 (21/21)	100 (19/19)	95 (19/20)	75–100 (n.a.)	n.a.	n.a.	n.a.
Abdomen	100 (3/3)	100 (1/1)	77 (10/13)	n.a.	n.a.	n.a.	n.a.
Extremities	64 (18/28)	100 (1/1)	n.a.	n.a.	n.a.	n.a.	n.a.
External	100 (2/2)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Overall	n.a.	n.a.	n.a.	n.a.	n.a.	60 (57/95)	74 (48/65)

n.a. not available

Data are presented as % (n/N): n number of injuries identified by CT, N number of injuries identified by autopsy, % percentage of identified injuries on PMCT

detect during conventional autopsy but more easily so with PMCT [29, 35, 38]. To minimize these missed injuries during autopsies some authors advocate specialized maneuvers during the autopsy like “opening the pericardial sac while keeping the organ submerged” or “by using an spirometer” (techniques to detect gas embolisms) [25, 33]. However, these methods are time consuming and not performed on a routine basis and therefore need frequent practice and education. As a consequence of the difficulty in diagnosing some injuries with autopsy, standard autopsy appears not to be a valid reference standard to test the performance of the PMCT in some cases [27]. To circumvent this problem some authors used the combined findings of PMCT and autopsy as a reference standard [27, 30], resulting in a relatively better performance for PMCT.

Injuries that are most frequently missed by CT are contusions or superficial lesions of solid organs, small soft tissue contusions, hematoma or emphysema, small brain contusions or hematoma (suggested to be smaller than 3 mm), and vessel transections or lacerations. Vessel injuries are often suspected owing to the presence of surrounding hematoma but the specific diagnosis cannot be made. The diagnosis of these injuries might benefit from other modern postmortem imaging techniques such as postmortem angiography [46]. For the detection of small brain contusions or hematomas we suppose that they are better detected on CT examinations with higher resolutions although no hard evidence for this conclusion is found within our review.

Although MRI is known to be more sensitive for distinguishing soft tissue injuries, we did not combine findings from PMCT with MRI because our interest was in the performance of PMCT as a single imaging strategy. Such a single strategy is more relevant for practice as PMCT is less time consuming, more available, cheaper, and easier to interpret than MRI. If MRI is preferred for the diagnosis of specific suspected (soft tissue) injuries it is always possible to perform an additional MRI on indication as suggested by one study [35].

For assessing the performance of PMCT alone we extracted the data specific for PMCT if reported as such in the article. If an article only reported combined findings from CT and MRI, we contacted the authors of these studies if they were able and willing to provide the CT findings only. Five authors were contacted because the data of the PMCT were combined with MRI data. We have subsequently received separate data on MRI and CT findings.

In most studies a standard CT protocol was used. However, the studies were performed between the period of 1994 and 2008, and the system types and the protocols used differed substantially between the studies. Several authors even claim that certain injuries were missed due to the poor resolution [28]. This emphasizes again the need for more standardized CT acquisition and image evaluation protocols in future studies.

In addition, all images were interpreted by radiologists. A drawback could be that not all radiologists are used to

interpreting postmortem radiology [32]. Therefore it is possible that findings were not mentioned by the radiologist because they were not familiar with certain postmortem findings [38]. To circumvent this bias, one protocol used both a radiologist and a trainee pathologist for interpretation of the findings on the CT examinations [34] and this was recommended by other authors [29]. Others suggest forensic training for radiologists [24, 38]. Although in this review no hard evidence for beneficial effects could be determined by these adjustments it should logically lead to a better performance of PMCT and we advise this in future study designs.

Finally, because in some studies a relative long period existed between CT and autopsy (reaching a maximum of 2 days), there is a possibility that some findings developed postmortem. Several authors describe their suspicion concerning such findings [28, 29, 33]. The first study described a distinct subdural hemorrhage detected by autopsy and not shown by CT. The second described intravascular air as a result of postmortem decay. Finally, the third study advocated that the low sensitivity of the PMCT for detecting intracranial hemorrhage and a distinct linear track through the brain after a high-velocity gunshot were a result of decomposition of the brain and subsequent breakdown of blood products. These considerations make it even harder to test the value of PMCT in trauma victims.

Overall, the many differences in study protocols and methods hamper the interpretation of the results. However, despite the fact that this review provides inconsistent evidence for PMCT being a reliable substitute for autopsy in determining the cause of death and specific injuries in trauma victims, in our opinion PMCT can be very useful. Since PMCT in most studies detects large numbers of injuries not seen at autopsy, this imaging method is a good adjunct to autopsy rather than a substitute. Furthermore preautopsy CT can be of guidance to the pathologist during the actual autopsy for specific injuries that are difficult to detect on autopsy alone. Other advantages of PMCT as a postmortem examination are that images can be saved for a long period and data can be studied repeatedly by different specialists. These advantages could potentially be of help in forensic cases [30]. Finally, in this time where autopsy numbers are still declining, PMCT can be an alternative for postmortem examination and an efficient method to obtain epidemiological data and clinical information contributing to optimal patient care. Larger, more standardized, and higher quality studies are needed to further examine the potential role and value of PMCT.

For these future studies we advise that researchers compare the blinded performance of CT with the performance of autopsy. Hereafter, but before closing the body during the autopsy, the CT findings should be revealed to complement the autopsy findings. These combined findings will then be the reference standard. The images should be interpreted by radiologists with forensic experience or assisted by pathologists according to a predefined general

injury classification. As an injury scoring system we suggest the worldwide accepted AIS for the description of sustained injuries. For the CT protocol we advise the use of high resolution CT images with multiplanar reconstructions. Another method would be to compare the blinded performance of PMCT and autopsy with a third imaging method such as MRI. However, because the value of MRI in postmortem examination is currently also under investigation, this is not the preferred method. Our last recommendation for future studies is a multicenter and international study design to equalize study protocols and increase the study population making subgroup analyses possible and providing high levels of evidence.

Conclusion

Current studies provide inconsistent evidence as to whether PMCT is a reliable alternative for autopsy in determining the cause of death in trauma victims. PMCT does have several promising features in postmortem examination. As a result PMCT should be used more as an adjunct rather

than an alternative to autopsy, because it can diagnose extra injuries which are hard to detect and therefore frequently overseen during conventional autopsies. To examine both the complementary (add-on) and replacement function of PMCT in postmortem examination of trauma victims, there is a need for well-designed and larger prospective studies.

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