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REVIEW AND PERSPECTIVES

State of the art in post-mortem computed tomography: a review of current literature

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Abstract

Computed tomography (CT) and other advanced diagnostic imaging techniques are gaining popularity in forensic pathology. This paper aims to define and offer complete and easily accessible "state of the art" for post-mortem computed tomography (PMCT), by reviewing the latest international literature. The proposed format answers the "five Ws" that follows: (1) What: We report the different kinds of CT scan and settings generally used in post-mortem imaging. The machine most employed is a 8/16-slice spiral CT, usually without contrast enhancement. The introduction of some variables, such as CT-guided biopsies, post-mortem ventilation, and PMCT angiography is becoming increasingly useful. (2) Why: Literature highlights the many advantages of PMCT. Limitations can be partly overcome by modern imaging techniques and combined evaluation with traditional autopsy. (3) Who: Most authors agree that collaboration between different specialists, i.e., radiologists and pathologists, is the best scenario, since radiologic, anatomic, and forensic skills are needed simultaneously. The most important human factor is "teamwork". (4) When: Literature provides no absolute limits for performing PMCT. Some authors have tested PMCT as a replacement for conventional autopsy but found some limitations. Others evaluated PMCT as a guide or screening tool for traditional autopsy. (5) Where: Many research groups around the world have performed studies on the use of PMCT. Although few countries adopt PMCT in routine practice, its use is rapidly spreading.

Keywords Post-mortem computed tomography · PMCT · Forensic radiology · Virtual autopsy

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Introduction

Post-mortem investigations have become increasingly interested in computed tomography (CT), and post-mortem computed tomography (PMCT) is now generally accepted[1]. Many scientific articles on PMCT have been published over the last few years[2] and several countries are routinely adopting this technique[3]. Numerous researchers are starting to get interested in this topic, but there is lack of easily accessible, updated literature that defines the "state of the art" for PMCT.

This is the aim of our review study through an evaluation of the latest international literature. The proposed format attempts to answer the "five Ws" (What happened? Who was involved? Where did it take place? When did it take place? Why did it happen?), all essential when gathering information and often mentioned in English language journals.

Literature search strategy

This literature review was carried out according to the preferred reporting items for systematic reviews (PRISMA[4]; Fig. 1). Its search was performed on the databases PubMed, Scopus, and Web of Science using different indexing terms (Table 1). An additional manual search was performed using the reference lists of the examined studies. The last search was conducted on October 2, 2018, including articles from January 1, 2008. Two reviewers independently screened the 4477 abstracts: they eliminated duplicates and adopted the following exclusion criteria:

- Non-English-language;
- Pediatric/neonatal casuistry;
- Animal models;
- Sample size inferior to 10 cases and case reports;
- Studies referring only to imaging techniques different from CT (MRI, PET…);
- Studies on the application of PMCT about the improvement of emergency life support.

Finally, they examined the full text of the remaining 482 studies to determine the eligibility for inclusion, excluding those with repetitive information. A third independent reviewer was contacted in case of disagreements. The final number of studies included in the current review was 81.

What is a PMCT and what kinds of tools are used?

The scanner most frequently used is a multi-slice spiral CT with a highly variable number of detectors (dual slice[5], 8 slices[6], 16 slices[7], 64 slices[8] up to 2 × 128 slices[9]). Slice thickness of acquisition is also variable: sub-millimetric slices in

Fig. 1 PRISMA flow diagram

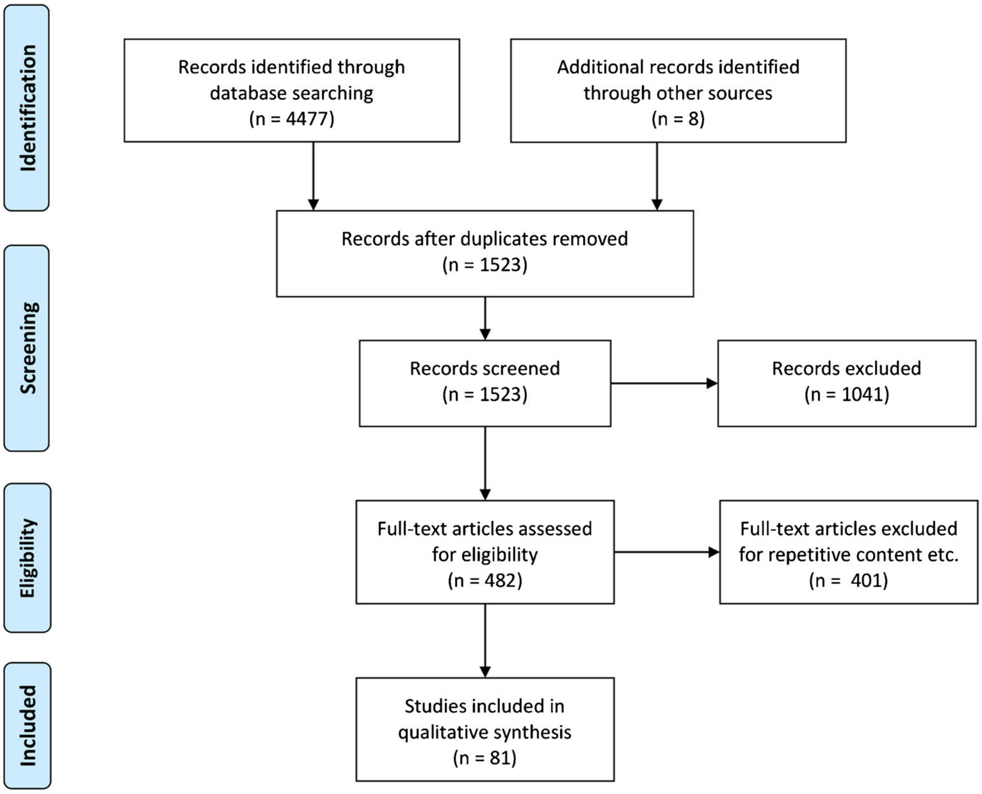


Table 1 Indexing terms

Indexing terms		Database		
		Pubmed (*n*)	Scopus (*n*)	Web of science (*n*)
(post-mortem[Title] OR postmortem[Title]) AND	Imaging[Title]	318	377	418
	Computed[Title] AND tomography[Title]	276	342	285
	CT[Title]	188	237	227
	Angiography[Title]	110	138	130
Forensic[Title] AND (computed[Title] OR tomography[Title] OR CT[Title] OR imaging[Title])		206	381	316
Virtual[Title] AND autopsy[Title]		53	71	66
PMCT		31	51	35
Virtopsy		39	62	42
Total		1241	1686	1550

the entire acquisition volume[10] for multi-planar reconstructions and volume rendering with high accuracy, or slices from 5 to 1 mm in specific areas of interest[6,8] (e.g. head), or for specific purposes (e.g. detection of fractures).

Other parameters (tube voltage, tube current-exposure time product, pitch, rotation time, windowing and kernel) need to be recalibrated for post-mortem studies to minimize noise and artifacts, to maximize contrast and spatial resolution. We report two scanner protocols: one using an old model CT (Danish group[5], Odense, with a Siemens Somatom Spirit dual-slice, Table 2), the other one operating a powerful scan (Virtopsy Group[9], Zurich, with a dual-source Somatom Flash Definition, 2 × 128 slice, three-step scanning protocol, Table 3).

It is noticeable that special programs are requested for specific areas (e.g., the neck); millimetric acquisitions and soft thin kernels are useful for multiplanar reconstructions, widely used at court.

Ideally, the supine corpse is placed in a body bag or preferably on plastic foil without metallic parts, to prevent any soiling or fluid leakage, and positioned in the center of the gantry to obtain the best image quality[11]. If possible, the head should be aligned along the body axis with the nose in a median position; artifacts and noise can be reduced for thoracic and abdominal scans by moving the arms above the head[9]. Any CT scanner can be used for autopsy if three conditions are met: provide a full scan range of the body and reconstruct both an extended field of view and the DICOM image, using an extended scale of Hounsfield units[12].

In the Virtopsy system[13], the CT scanner and table are located within reach of a ceiling-mounted robot arm. A CT-guided needle-positioning robot allows tissue sampling of focal organ lesions with an accuracy of less than 2 mm[14]. In a study on 20 bodies[15] examined by biopsy sampling in association with PMCT, this minimally invasive approach led to a consistent increase in sensitivity to ascertain the correct cause of death (18 out of 20 selected cases). Two major drawbacks of PMCT regard the study of the lungs and circulatory system. Consequently, two variants are under evaluation to overcome these limitations.

PMCT with lung ventilation

Recognition and correct interpretation of the numerous changes in the lungs are essential in establishing the cause of death[16]. The experimental technique of ventilated PMCT could produce better pulmonary images due to improved differentiation between post-mortem changes and pathologic findings in collapsed pulmonary parenchyma[17], as well as discriminating between consolidation, ground glass attenuation and position-dependent density. The dorsal part of the lungs (position-dependent density) and ground glass

Table 2 Protocols used by the Danish group, Odense, with a Siemens Somatom Spirit dual-slice. kV, kilovolt; mA, milliampere

Step	kV	mA	Pitch	Rotation time	Slice	Collimation	Kernel
1) Head	130	110	0.95	1.5 s	1 mm	1 mm	Median smooth H31 Sharp H60
2) Neck	130	110	0.95	1.5 s	3 mm	2.5 mm	Median sharp B50
3) Thorax	130	60	1.8	1.0 s	5 mm	2.5 mm	Median smooth B31 Highres B70
4) Abdomen	130	80	1.8	1.0 s	5 mm	1.5 mm	Median B41
5) Extremities	130	30	1	1.0 s	3 mm	2.5 mm	Ultra highres U90

Table 3 The three-step scanning protocol used by the Virtopsy Group, Zurich, with dual-source Somatom Flash Definition, 2 × 128 slices

Step	kV	mA	Pitch	Rotation time	Slice (mm)	Collimation (mm)	Kernel	Orientation	Window	Field of view (mm)
1) Whole body "the baseline"										
Whole body	120	400	0.35	0.5 s	2	1	Soft B30	Axial	Abdominal	eFov
Whole body					2	1	Hard B50	Axial	Osteo	eFov
Whole body					3	2	Soft B30	Coronal 3D	Abdominal	eFov
2) Head and neck										
Head and neck	120	400	0.35	0.5 s	0.6	0.4	Soft H31	Axial	Cerebrum	300
Head and neck					0.6	0.4	Hard H60	Axial	Osteo	300
Head					4	3	Soft H31	Axial 3D	Cerebrum	300
Head					0.6	0.4	Soft H31	Axial 3D	Cerebrum	300
Head					0.6	0.4	Hard H70	Axial 3D	Osteo	300
Cervical spine					1.5	1	Hard H60	Axial 3D	Osteo	Small
Cervical spine					1.5	1	Hard H60	Coronal 3D	Osteo	Small
Cervical spine					1.5	1	Hard H60	Sagittal 3D	Osteo	Small
3) Thorax and abdomen										
Th & Ab	120	400	0.35	0.5 s	1	0.6	Soft B30	Axial	Abdomen	500
Th & Ab					1	0.6	Hard B60	Axial	Lung	500
Th & Ab					5	3	Soft B30	Axial	Abdomen	500
T/L spine					1.5	1	Hard B70	Axial 3D	Osteo	Small
T/L spine					1.5	1	Hard B70	Sagittal 3D	Osteo	Small
T/L spine					1.5	1	Hard B70	Coronal 3D	Osteo	Small
Sternum					1.5	1	Hard B70	Sagittal 3D	Osteo	Small
Pelvis					1.5	1	Hard B70	Coronal 3D	Osteo	Small

kV, kilovolt

mA, milliampere

eFOV, extended field of view

3D, three-dimensional angulated reconstruction

Th & Ab, thorax and abdomen

T/L spine, thoracic and lumbar spine

attenuation (liquid in the interstitial spaces) show a reduction in density, whereas the consolidated areas remain unattenuated[18]. Ventilation is usually performed using a home-care ventilator applied to various airway accesses: an endotracheal tube, continuous positive airway pressure, or larynx mask for a supra-glottic airway to a modified endo-tracheal tube through crico-thyroidectomy (a decision-making algorithm is available)[19]. The most common technique is to apply an intermittent[20] or continuous[18] pressure of 40 mbar.

PMCT angiography

Unenhanced post-mortem imaging is not considered sufficient to visualize vascular pathology[21], due to very low sensitivity. The principle of PMCTA is to inject a contrast agent (CA) into the vascular system to enhance PMCT diagnostic power. Several materials and techniques have been proposed and in 2012 an international working group called the "Technical Working Group Post-mortem Angiography Methods" was created to investigate the performance of PMCTA and to develop and validate its techniques[22]; an extensive discussion is beyond the scope of this work. The post-mortem vascular system is empty or partly filled with blood clots: a high volume of liquid perfused under a certain pressure is required[23]. Since the CA cannot pass through the degenerated capillary anastomoses, an arterial injection (and scan) must be followed by a venous injection (and scan)[9]. Various sites of injection are used (femoral[9], carotid[24], axillary and subclavian vessels). Infusion is performed manually (although it is difficult to maintain the correct pressure for the entire perfusion), or by a modified heart-lung machine[25], cardio-pulmonary resuscitation proceedings[26] (thoracic compression) or else by specifically-designed pressure-controlled perfusion devices (e.g., Virtangio®)[27]. A further setback is the increase in permeability of the vascular wall. A hydro-soluble CA rapidly spreads into adjacent tissues causing edema and artifacts during histology and must, therefore, first be dissolved in a high viscosity solvent (e.g., poly-ethylene glycol at 65% concentration, 18 mPas[23]). Due to molecular polymerization, extravasation is limited with optimal tissue enhancement[28], although in a few cases it may attract water from the surrounding tissues and clump the remaining blood in the vessels, masking thrombosis[29]. The alternative is an oily CA mixture, varying in viscosity. Low viscosity diminishes the diameter of the embolized vessels[30] but artefactual extravasation may be observed, whereas high viscosity leads to lack of contrast in microvascular structures and organ parenchyma. One proposal from Lausanne (Switzerland) suggests a mixture of paraffin oil and 6% Angiofil® which seems to have balanced qualities[27].

Although PMCTA and traditional autopsy reach similar conclusions regarding the cause of death, PMCTA demonstrates higher sensitivity in identifying skeletal and vascular lesions, whereas traditional autopsy provides more information on organ gross anatomy and pathology[31].

Why is PMCT performed?

In this paragraph, a synopsis is proposed regarding the advantages and limitations of PMCT, its role in defining the cause of death, post-mortem interval, and personal identification.

Sensitivity, advantages, and limitations

The advantages and limitations of PCMT are listed in Table 4[32].

In traumatic deaths, the usefulness of the technique has been widely reported: it detects major injuries seen at autopsy disclosing most primary and significant causes of death[33]. In particular, for skeletal injuries PMCT has great sensitivity, superior to that of an autopsy[5]. In poly-traumatic cases (e.g., car accidents), analysis of the morphology of fractures can supply information on the dynamics of the implied forces, allowing better reconstruction of the accident[34] (Fig. 2). Despite low sensitivity for rib fracture recognition, partial fractures are better identified by PMCT than by routine autopsy, thereby increasing overall sensitivity[35].

Another strong point for PMCT is the detection of gas collection, almost always missed by autopsy, and a robust concordance is seen for major blood collections such us hemothorax[33]. For the detection of traumatic organ lesions, the sensitivity is not high, almost 50% (the highest and the lowest sensitivity are reported for hepatic and pancreatic injuries, 71% and 12% respectively[36]), but they are often suspected owing to the presence of a surrounding hematoma (Fig. 3).

The study of gunshot wounds is also an important field of application. PMCT can easily detect retained bullets or fragments as well as destructive effects on the body (fractures, hemorrhages, soft tissue emphysema). It can also contribute to the correct prediction of the gunshot wound tracks and even give some information about the firing range (in contact-range by the expansion of the skin, and in intermediate-range by detecting gunshot residues)[37,38]. In the case of stab wounds, PMCT is a valuable tool in recognizing deep wound channels

Table 4 PMCT advantages and limitations

PMCT advantages

1 “Non-destructive” documentation: it does not preclude other forensic investigation and can be used in cultures where religion or family members will not accept traditional autopsy

2 Safe examination of bodies contaminated by infection, toxic substances, radionuclides or other biohazards. A minimally-invasive method for screening prior to conventional autopsy in high-risk cases

3 Ideal bone visualization (e.g., fracture pattern), lung parenchyma disease, calcifications (stones, atherosclerosis), acute hemorrhage, air/gas (e.g., pneumothorax, pneumatosis intestinalis, free air)

4 Easy identification of foreign bodies and anatomical positions

5 Evaluation of body parts not explored in routine autopsy

6 2D and 3D post-processing helps visualize findings for interested parties not attending the examination (e.g., in court, CT images are better tolerated than autopsy images)

7 Easily-retrievable digital archives permit re-evaluation of the images in light of new data and teleconsultation/s opinion

8 Possibility of biopsy guidance

9 Good availability: CT is widespread throughout the world

PMCT limitations

1 Limited availability during regular working hours (interferes with scanning of hospital patients if a scanner is not completely dedicated to this purpose)

2 Limited visualization of pathology in soft tissues and organ parenchyma

3 Limited differentiation of normal post-mortem changes (e.g., clotting, sedimentation) and pathology (e.g., pulmonary thromboembolism)

4 Limited ability to diagnose cardiac causes of death (e.g., patency of coronaries, acute myocardial infarction)

5 Image artifacts (e.g., metal from dental filling, prosthetic valves)

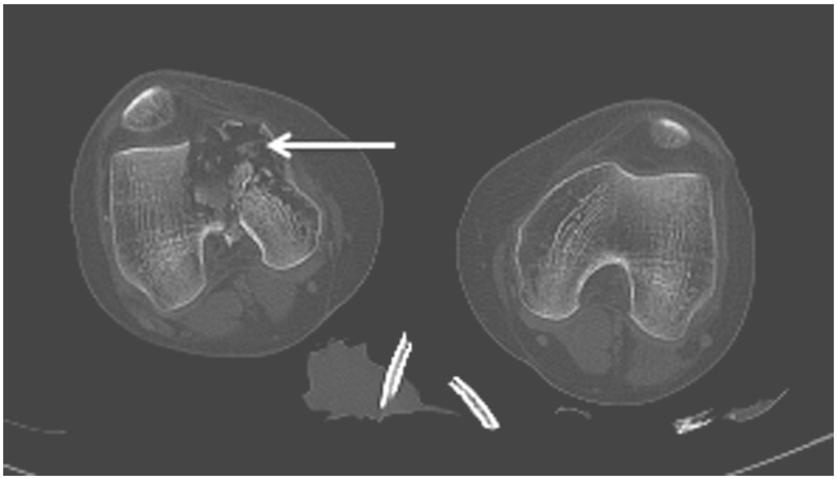


Fig. 2 Femur fracture with posterior dislocation of fragments indicating an antero-posterior stress (like a bump with a fender). PMCT allows considerations about the pathogenesis force of the fracture

and related injured structures, whereas superficial stab wound channels and cuts are frequently missed[39].

PMCT appears to have a better sensitivity in detecting tracheobronchial contents, which can be displaced by mobilization of the body during autopsy[40].

In fire-related deaths, PMCT shows typical signs of heat injuries, such as thermal fractures and amputations, skeletal muscle retraction, thermal epidural hematoma and heat destruction of soft tissues, and enables evaluation of occult ante-mortem pathologic processes or injuries and remnants of unsuspected objects[41]. Thanks to ante-mortem images, this technique can also provide evidence of fatal complications due to medical malpractice (misplaced catheters, guide-wires, tubes and drainages, hemorrhages and gas embolism)[42].

PMCT can supply characteristic findings of death by freshwater drowning[43]. These include hemodilution (low blood radiodensity), emphysema aquosum (mosaic pattern of hypo- and hyperperfused lung areas together with lower position of the diaphragm), paranasal and tracheal fluid collection. Although these findings are not specific, they are highly suggestive of drowning. It has recently been assessed that the most statistically relevant signs are the reduced distance between the lungs and the decreased density of gastric contents with increase of stomach volume[44].

In natural causes of death, the most common discrepancies between CT and autopsy regard the diagnosis of pulmonary embolism, overlooked by non-enhanced PMCT in 100% cases. Other diagnoses frequently missed by CT alone are cases of esophageal varices, and non-perforated gastrointestinal ulcerations[5].

In cases of sudden cardiac death, PMCT sensitivity is low in recognizing coronary stenosis, coronary thrombosis, acute myocardial infarction, fibrotic myocardial scar[5], but high in identifying calcification of coronary arteries (Fig. 4) or valves[45] and hypertrophic or dilated cardiomyopathy[46].

Lastly, even other pathologic states such as pneumonia, gastrointestinal ischemia, sepsis, and multi-organ failure are frequently not identified by PMCT alone[47].

Although current literature is not sufficient to assess exact PMCT sensitivity for the various causes of death[48] in certain subgroups significant differences regarding detection rates between PMCT and traditional autopsy are evident: the highest

Fig. 3 A splenic rupture is highly suspected in the presence of a peri-splenic hematic collection (as well as a hepatic lesion due to hyperdense peri-hepatic fluid)

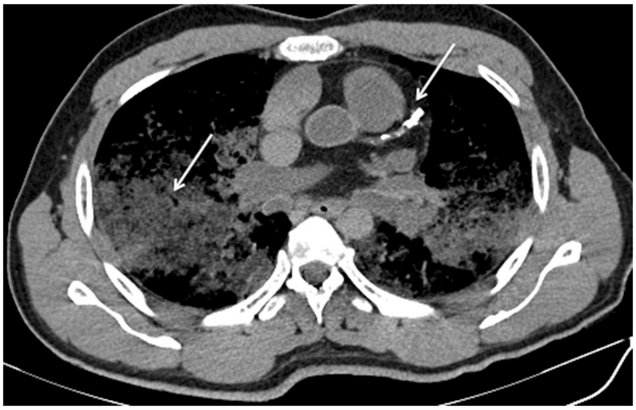


Fig. 4 The detection of calcific coronaropathy (right arrow) and smooth thickness of interstitial pulmonary spaces (left arrow) in a sudden death is suspicious of acute myocardial infarction

and lowest agreement on the causes of death concern injuries and natural deaths, respectively[49]. However, PMCT rarely determines the cause of death, whereas in most cases it provides indirect or nonspecific cues, suggesting the cause of death that needs to be confirmed by autopsy[50].

PMCT to estimate post-mortem interval

Preliminary studies suggest that post-mortem changes identified by CT may provide an index for objective estimation of the post-mortem interval. PMCT images reveal a decrease of intrarectal gas and an increase of intrahepatic gas[51], a time-dependent attenuation gradient of ground glass opacities in the dependent lung regions[16] and a non-linear increase of cerebrospinal fluid density[52]. However, actual data need validation and standardization to have a concrete role in the estimation of the Post-Mortem Interval.

PMCT as a tool for personal identification of a body

PMCT can help forensic odontologists by providing a full dental scan, showing prosthetic materials, and can be used for comparison with ante-mortem data[53]. Similarly, the paranasal sinuses can be used for radiologic comparison by virtue of their high interpersonal variability[54]. Encouraging results have also been obtained through the fusion of thoracic ante-mortem images with PMCT after comparison of specific bone and soft tissue points[55]. PMCT can easily visualize foreign bodies and metal prostheses decisive for diagnosis[9].

Regarding age estimation, PMCT can supply information on the eruption of teeth, skeletal accretion and metaphyseal fusions[56]. The stage of ossification of the clavicle is particularly useful in subjects between 10 and 35 years[57], while shape analysis of the femurs can provide a rough estimate[58]. Rib cartilages, scapula, skull and pubic symphysis also serve the same purpose[59]. In odontology, if a volumetric imaging technique is adopted, the shrinkage of the pulp chamber is a further reliable parameter to better estimate the age[60].

Finally, for gender determination, PMCT is a reliable tool in establishing typical skeletal dimorphism, primarily of the cranium or pelvis, but also of the femoral head[59], radius, sternum[61], scapula[62] or mandible[63].

Who should evaluate the images (which specialists are involved in PMCT)?

A current debate in literature concerns who should interpret PMCT images. On one hand, the pathologist knows which findings are important to establish the cause of death but does not usually have a radiological background, while on the other hand the radiologist knows how to recognize them but may mistake findings with normal post-mortem changes. Teamwork is always recommended[12] and for the development of post-mortem imaging it is necessary that whoever approaches PMCT should be a dedicated and specifically-trained professional. Currently, there is still no established curriculum for this new subspecialty but the International Society of Forensic Radiology and Imaging was founded in 2013 to address this specific topic[64.]

The European Council of Legal Medicine expressing standards for forensic pathology services in Europe considers services in Europe considers it an absolute requirement that CT images should be evaluated by a "*board-certified radiologist with a minimal experience in forensic radiology*"[65].

Double analysis of CT findings[66] in 67 traffic victims was conducted by a board-certified clinical radiologist and a pathologist with five-year experience in PMCT. Inter-observer variability was low since the radiologist identified more injuries, particularly in the skeletal system, whereas the pathologist diagnosed more organ injuries from post-mortem changes.

When is PMCT necessary or advisable?

The combination of post-mortem imaging and conventional autopsy is now the gold standard accepted all over the world and practiced in many countries[48]. However, clinical and forensic autopsies differ in certain aspects.

PMCT in clinical autopsy

Clinical autopsies are performed to diagnose the cause of death when ante-mortem efforts have failed or to study the disease process in situ if the cause of death is known. They need the consent of next of kin and their numbers in Europe and the USA have fallen considerably over the last few years also for family reluctance and religious or ideological opposition to post-mortem investigation[67].

In this context post-mortem imaging can be seen as a resource.

As some studies have shown that CT alone cannot always diagnose common causes of natural death (see paragraph 3.1) without biopsy, the interest of clinical pathology has turned towards the application of an association of PMCT to a minimally-invasive autopsy, followed by multiple organ biopsies. Autopsy studies conducted on adult patients deceased in hospital revealed no significant differences between this method and a classical autopsy regarding identification of cause of death and answers to clinical queries (92% agreement in cause of death)[68]. Therefore, in selected cases, minimally-invasive autopsy may replace traditional autopsy; further studies seem needed to confirm these results and their applicability.

Surely the combination of PMCT and traditional autopsy enhances the diagnostic quality and completeness of the clinical autopsy report by a documentation of pathologic findings,

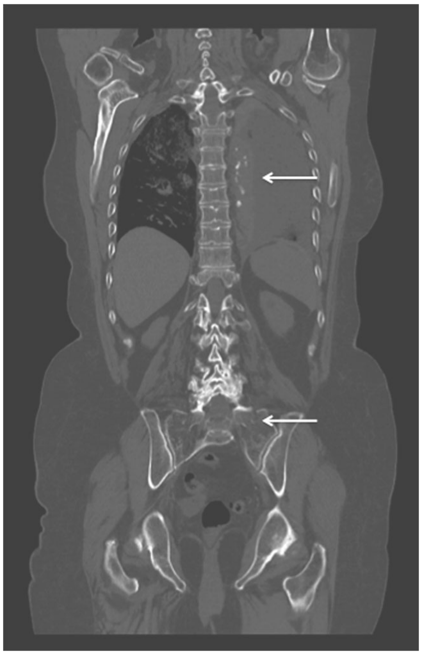


Fig. 5 Massive hemothorax (probably originating from the aorta) and hip fractures. Before autopsy, PMCT provides a quick overview of the body, focusing the attention of the pathologist on specific areas of interest

especially calcified lesions of the cardiovascular system, bone fractures, lesions of the musculoskeletal system, air accumulations and herniations[46].

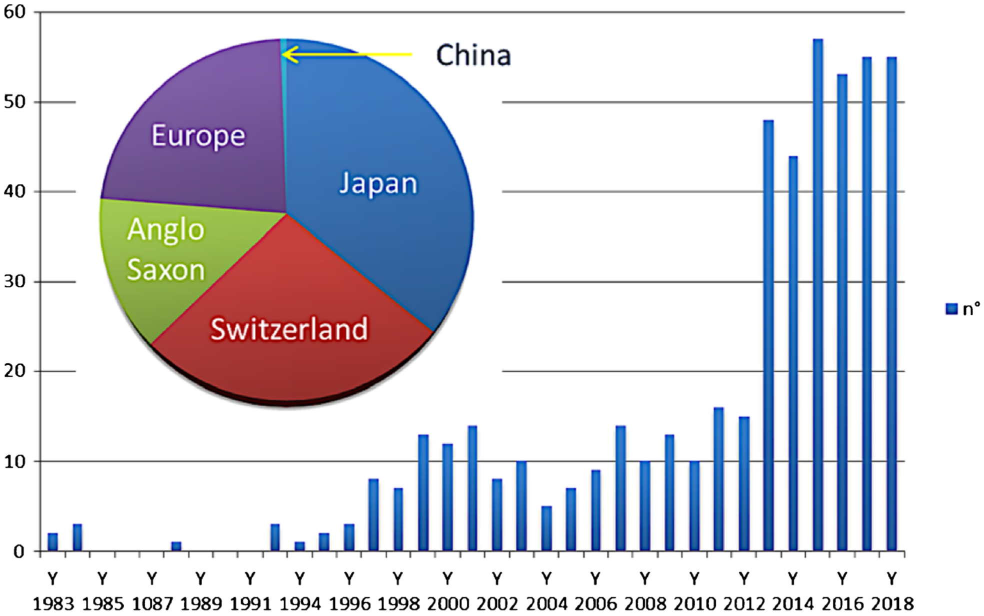
PMCT in forensic autopsy

Forensic/legal autopsy does not require consent; it is mandatory by law or requested by the prosecutor/judge/coroner. It is performed to answer questions on identity, cause and time of death, manner and circumstances, to collect trace evidence and help law-enforcing agencies solve the crime. Forensic indications for PM imaging can vary from institution to institution and from country to country. In those forensic pathology centers where imaging is more customary, like Switzerland or Australia, PMCT is a baseline examination, carried out on all bodies delivered to the morgue, and depending on the results, the pathologist will request autopsy, toxicological analysis or further examinations[9]. Many protocols and guidelines for performance standards adopted worldwide by Forensic Societies support the use of forensic radiology to complement autopsy investigation[69]. PMCT allows objective, permanent, and non-invasive documentation of internal and external body injuries in addition to autopsy[6] and can direct it by providing a quick 3D overview of the body, including areas not routinely investigated by autopsy (face, pelvis, etc.; Fig. 5)[70].

Where (i.e., in which countries) is PMCT routinely used?

Over the last 10 years, the use of PMCT has spread all over the world. Most literature on this topic comes from Japan and Switzerland (Fig. 6) and the scientific interest on post-mortem imaging may reflect PMCT use proportionally. In Japan, where CT-unit distribution is high and autopsy rate low, PMCT has been carried out since 1985. The Society for Autopsy Imaging was founded in 2003 and now no fewer than 20,000 PMCT are performed per year[26]. Switzerland is one of the most advanced countries for forensic radiology. The "Virtopsy project" was born at the University of Bern to compare images with autopsy findings. Optical surface scanning, a

Fig. 6 Countries of origin of PMCT articles published from year 1983 to 2018 and number (no) of articles for each country. Japan (131), Switzerland (96), Anglo-Saxon countries (50), rest of Europe (84), and China (3)



MSCT and MRI were used[71] and now the techniques of PM-ventilation and angiography are tools of daily forensic practice[23,72]. In European countries PMCT use is developing differently. In the Netherlands in 2000, a cooperation between various forensic centers and the radiology department of the Groene Hart Hospital in Gouda started[10]. We found many papers from Germany[73] where post-mortem imaging research is also carried out in cooperation with Switzerland (by the Institute of Legal Medicine and Forensic Sciences at Charité-Universitätsmedizin Berlin[74]). PMCT is routinely performed on a broad scale in Denmark[3], most of all in Copenhagen and Southern Denmark Universities and in the Institute of Forensic Medicine at Odense[75]. France also routinely adopts PMCT, in particular at the Rouen University Hospital Department of Forensic Medicine and at the University of Strasbourg[7] in order to obtain anatomical–radiological correlations[76]. We found various Italian international cooperation studies[16,77]. Moreover, we know PMCT is often performed in various towns, such as Rome, Palermo, Pisa, and Florence. A large number of papers are from Anglo-Saxon countries (UK, USA, Australia). A PM diagnostic center was set up in Leicester University Hospital[78] at the end of 2017 and in Manchester a PM-imaging service for selected non-suspicious deaths was introduced in the 1990s. This was due to the requests of the Jewish and Muslim communities in the northwest of England[6]. In the USA, there are currently three medical examiner offices where advanced postmortem imaging is carried out: the Armed Forces Medical Examiner in Dover, Delaware; the Medical Investigator in Albuquerque; and the Chief Medical Examiner in Baltimore[79]. Moreover, at the Division of Emergency Radiology in Indianapolis, a PMCT was used to identify autopsy-occult injuries and to complete the trauma registry[80]. At the Armed Forces Institute of Pathology, Washington D.C., PMCT is performed only on military personnel[3]. In Australia, CT scanning is an intrinsic component of the workup of all admissions to the Victorian Institute of Forensic Medicine, to decide if traditional autopsy should take place or not[3]. The number of studies from China on this topic is low, mostly case reports, despite the size of the country: from a general point of view forensic imaging seems currently to still be in a developmental stage, however the Institute of Forensic Science of Shanghai begins to carry out research on post-mortem imaging[81].

Conclusions

The "take-home points" of this review are outlined below:

1) What: PMCT is an additional test that can greatly increase the quality and efficacy of autopsy.
2) Why: PMCT is a non-invasive, rapid, objective procedure that highlights features not always detectable in traditional autopsy, through permanent, easily-accessible documentation, and 3D-image processing.
3) Who: PMCT should always be carried out by radiologists and pathologists in close collaboration.
4) When: PMCT is always performed before a traditional autopsy or as a screening test for it.
5) Where: PMCT is now being used regularly in many parts of the world.

Contributions Dr. Niccolò Norberti, Dr. Paolina Tonelli, and Prof. Stefano Colagrande conceived and designed the study, and wrote, edited and reviewed the manuscript.

Dr. Claudia Giaconi, Dr. Cosimo Nardi, Dr. Marina Focardi, Prof. Gabriella Nesi, and Dr. Vittorio Miele wrote edited and reviewed the manuscript.

All authors gave final approval for publication.

Dr. Niccolò Norberti takes full responsibility for the work as a whole, including the study design, access to data and the decision to submit and publish the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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