Radiol med (2015) 120:846–855
DOI 10.1007/s11547-015-0529-x

ETHICS AND FORENSIC RADIOLOGY

Imaging for homicide investigations

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Received: 30 December 2014 / Accepted: 24 February 2015 / Published online: 17 March 2015

Abstract The authors present the opportunities of the application of post-mortem imaging, focusing on post-mortem computed tomography and post-mortem computed tomography angiography in modern forensic investigation of homicide cases. The paper is based on scientific publications related to the subject from ca. the past 10 years, supplemented by the authors' own experiences. The article is illustrated with reconstructions based on the authors' own cases related to homicide due to ballistic/sharp/blunt trauma. As is shown, the results of evaluation of post-mortem computed tomography allow better diagnosis, documentation and visualisation of forensic examinations.

Keywords Post-mortem examination · Forensic autopsy · Forensic radiology · Post-mortem computed tomography · Homicide investigation

Introduction

In everyday clinical work, it is obvious that any doctor's activities regarding the patient have to be reported accordingly in medical records. However, it is possible that these annotations will never be analysed by anybody else. In contrast, in the field of forensic medicine, we are practically assured that all of our reports will be scrutinised thoroughly. This applies especially to autopsy reports—written results of examination of material evidence mainly in penal cases. Due to the fact that a very special kind of evidence is under examination—the human corpse, it is only possible to do it completely once: any consecutive examination will have limitations due to previous autopsy procedures as well as changes due to decomposition, and in some cases it would even be impossible to repeat the examination due to cremation of the corpse. This means that the autopsy report is the only source of obtainable information referring to the physical state of the deceased person. Therefore, it gives us a special responsibility to prepare the autopsy report in, as much as possible, an objectified way. Registration of images acquired during conventional post-mortem examination (photographs, films) gives additional value to the records. At present, due to technological developments, we have another opportunity to take advantage of different means of digital data collection, enabling us to register the actual state of the cadaver (in three dimensions—3D) before it is changed due to conventional autopsy procedures, including photogrammetry and laser scanning, post-mortem computed tomography (PMCT), and post-mortem magnetic resonance imaging (PMMR) [1–4]. These methods are related to the registration of both external and internal changes, giving us the unique opportunity to make the autopsy—which can be performed fully only once—into a kind of repeatable examination, with the ability to analyse the same information at a later time. The sensitivity of these diagnostic methods gives us a chance to reinforce the conventional post-mortem examination, which, as a whole, is not very different from when it was performed in the nineteenth century [5, 6].

The value of homicide investigations in the field of forensic pathology

Forensic post-mortem examination is generally ordered in different cases of suspected death. Among them there are a

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considerable number of autopsied cases related to accidental violent death, as well as sudden and unexpected death due to disease. However, the most complicated cases are mostly related to suspected homicides. As is widely known for forensic pathologists, the purpose of forensic autopsy is not only to reveal the actual cause of death, but to secure evidence related to other important problems, including estimation of the time of death, verification of the identity of the victim, recording the injury patterns, identification of the weapon of crime, etc. The data obtained during post-mortem examination, combined with the information from the files of the case, are necessary for the forensic reconstruction of the event.

Post-mortem imaging in modern forensic investigation of death cases

Laser scanning and photogrammetry are methods useful not only for registration of external body changes (they are the best for this purpose), but also for gathering valuable data from the scene where the body was found, as well as relating to the possible weapon of crime [7, 8]. The procedure of these methods of surface scanning can be standardised through automation by the use of a robot [9]. By comparing with further investigation data, a reconstruction of the event can be shown [10, 11].

Regarding internal examination, it refers to PMCT and PMMR. PMCT, because of speed and accessibility, is definitely more useful as a screening method, especially when multiple fractures and foreign objects are considered. PMMR, on the other hand, is much more time consuming and expensive, but it is of a bigger efficiency when it comes to evaluating changes in soft tissues. As is readily understood, the availability of PMCT is definitely more popular. The rest of the article will refer mostly to the utilisation of PMCT.

PMCT in homicide cases

There are three main purposes for the application of PMCT: (1) diagnosis, (2) identification [12, 13] and (3) documentation.

1. Diagnosis: PMCT acquisition prior to conventional autopsy examination gives us the opportunity to make a primary evaluation [14] before a conventional autopsy examination is started: to analyse the results, focusing on locations less accessible for conventional examination techniques [15] (e.g. the facial part of the skull, cervical spine (Fig. 1), extremities, pelvic region) as well as the possible presence of foreign bodies (Fig. 2), including lodged projectiles (Fig. 3) important to be recovered during autopsy examination. Such analysis has an important role especially in cases of damaged cadavers (burnt, decomposed, fragmented). Ampanozi et al. [16] reported the finding of an occult gunshot wound of the face with pieces of the projectile (it was irrelevant to the actual cause of death—tension pneumothorax). In some cases, the findings can even lead to primary conclusions about the cause of the (violent) death (aspiration of blood [17], haemopericardium [18]—as in fresh corpses we are able to differentiate body fluids [19]). There are even changes related to the cause of death more likely to be proven by the results of PMCT, such as pneumothorax (Fig. 4a), including tension pneumothorax (Fig. 4b) [20].
2. Identification: we can obtain vital information for exclusion/non-exclusion of the identity of the deceased person by comparison of registration of items of clothing, personal belongings, piercings, the shape of the ears, bone features [21, 22] (facial appearance [23], paranasal sinuses, healed fractures), signs of previous medical interventions (internal fracture stabilizations, pacemakers, etc.), dental features [24–26] and even characteristic changes due to disease (arteriosclerosis, aneurysms, cysts, lithiasis, etc.). However, it should be stressed that the most relevant method of positive identification of the deceased person is based on DNA sampling.
3. Documentation: of the obtained information can be stored and re-evaluated when new facts come to light.

Fig. 1 Thick maximum intensity projection (MIP) in axial plane based on native PMCT, showing injuries due to blunt trauma: fractures of the first cervical vertebra (atlas) at the left side, fragmentation of the *left side* of the mandible (*arrows*)

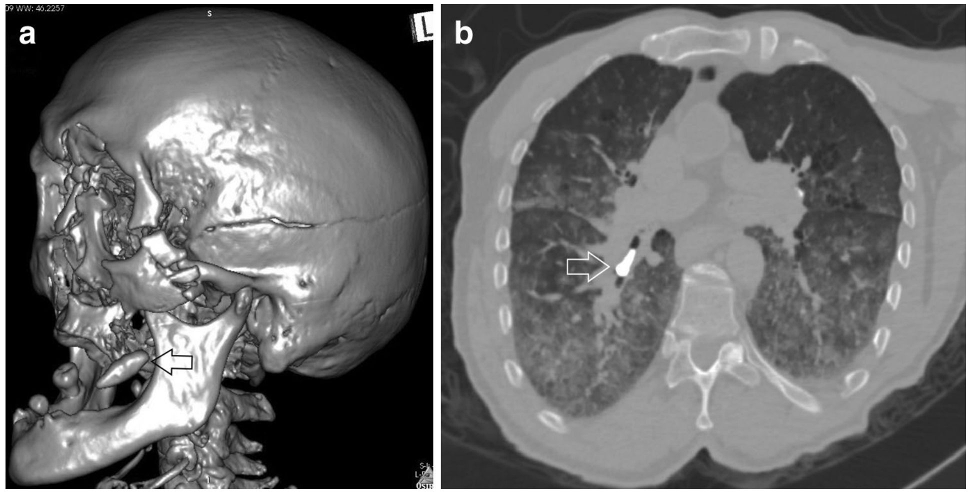

Fig. 2 A case of a victim of homicide due to blunt trauma to the head: **a** volume rendering technique (VRT) reconstruction based on native PMCT, left anterior view—fragmentation of the facial part of the skull with the line of fracture going to the back part of the skull, tooth dislocation (*arrow*), **b** thin MIP in oblique axial plane showing aspiration of blood and a foreign body—the tooth on the *right side* (*arrow*)

Fig. 3 Axial slice based on native PMCT—the neck of a victim of homicide with subsequent burning of the corpse: lack of integuments, fractured mandible, a foreign body (the projectile) at the back (*arrow*)

This can even be done remotely by other doctors. PMCT data give us the opportunity to make a visualisation of both external (mostly localisation without specific features, due to limitation of the method) and internal changes, which can be understandable and emotionally secure for non-professionals. It gives us the opportunity to use 3D reconstructions as demonstrative tools [27, 28]. Eventually, it will be possible to prepare models by 3D printing for better understanding of important aspects of forensic investigation [29].

Gunshot injuries

At the present time, we can strongly state that the gold standard for forensic post-mortem examination in cases of gunshot injury is forensic radiology combined with conventional autopsy. The PMCT examination has to be performed prior to conventional autopsy (both external and internal examination)—in some cases the best order would be PMCT between conventional external and internal examination. The possibility of finding the location of external injuries in PMCT examination is more likely when the wounds are located in the anterior or sides of the body when the corpse was lying “face up” during acquisition, without covering by layers of clothing soaked with blood. With regard to “native” PMCT (examination without administration of contrast medium), areas with injuries can be found by the presence of air bubbles, bleeding foci and small foreign bodies (e.g. fragments of the bullet). This allows areas of external injuries (entrance/exit wounds) to be shown for the 3D visualisation. In a number of cases, the results of native PMCT can help with the differentiation between the entrance and the exit wounds: by the shape of injuries, comparison between (two) external injuries on different sides (areas) of the corpse and the location of displaced pieces of broken bones. By the bevelling of bone fractures, we are able to indicate the direction of a gunshot. Pieces of unburnt powder can indicate cases of immediate vicinity shots. With the application of PMCT—angiography (PMCTA) [30, 31], we have the opportunity to see the location of wounds by focal extravasation of contrast medium. Metal objects (such as lodged projectiles) can be indicated quite easily in native PMCT—recovered projectiles are valuable pieces of evidence. In many cases, it is easy to obtain the pattern of the whole injury track of the head if there are injuries of the skull especially with

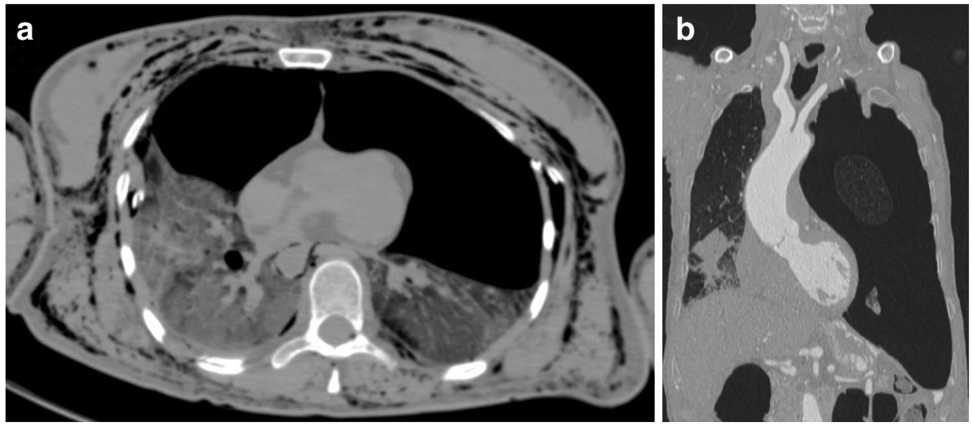

Fig. 4 Cases of pneumothorax: **a** thin MIP in axial plane of a victim of homicide due to multiple blunt injuries to thorax—fractured ribs on both sides, bilateral pneumothorax, collapsed lungs, gas spaces between layers of soft tissue of the chest, **b** thin MIP in coronal plane based on PMCTA at the arterial phase: tension pneumothorax on the *left*

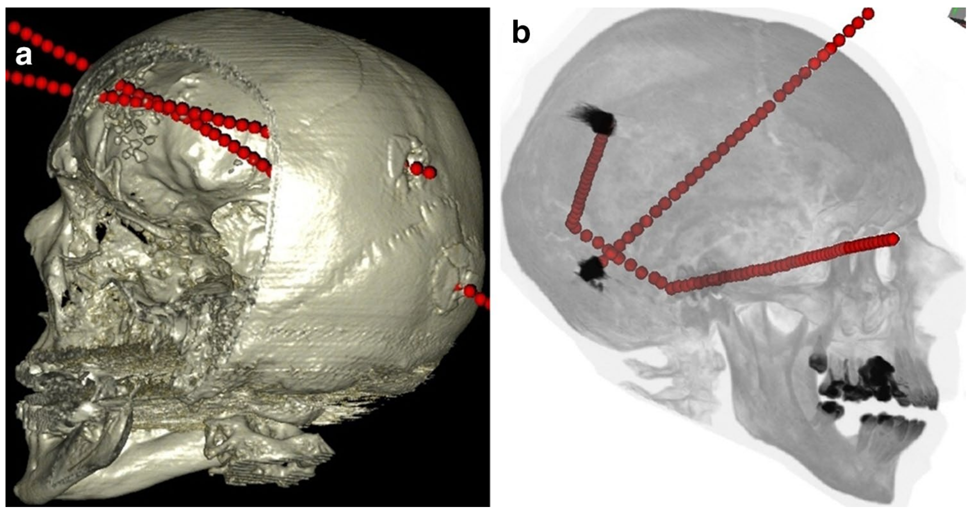

Fig. 5 Bullet trajectory reconstructions: **a** VRT reconstruction based on native PMCT after virtual removal of the *left side* of the skull, *left* posterior view: two bullet paths schematically shown in *dots*, **b** MIP reconstruction based on native PMCT, lateral view of the skull with two bullet paths—including one with double deflection of the projectile; both projectiles lodged inside the skull

unilateral bevelling (Fig. 5a). Injuries of the brain at the location of cavitation (with air bubbles, pieces of broken bone, or even blood) can be shown based on native PMCT. The opportunity to estimate the injury track, based on native PMCT, can be similar in some cases of chest injury. The most problematic are missile injuries of the abdomen.

In some cases, the direction of fire does not simply reflect the closest path between the entrance wound and the location of the missile/exit wound, because the bullet can be deflected due to contact with bones. Bouncing of the missile can be evaluated by the results of the native PMCT (Fig. 5b). In other cases, we can obtain the result that the projectile is lodged at a distant location to what was expected—due to "migration" prevalently inside vessels with blood. With the application of the PMCTA, we have the opportunity to visualise the actual injury track (Fig. 6). Due to contrast medium leakage, it is possible to reveal damage to vessels and internal organs. Ruder et al. [32] reported PMCTA in a case of firearm injury of the heart.

The papers referring to the post-mortem imaging in ballistic trauma are scoped on feasibility of the methods

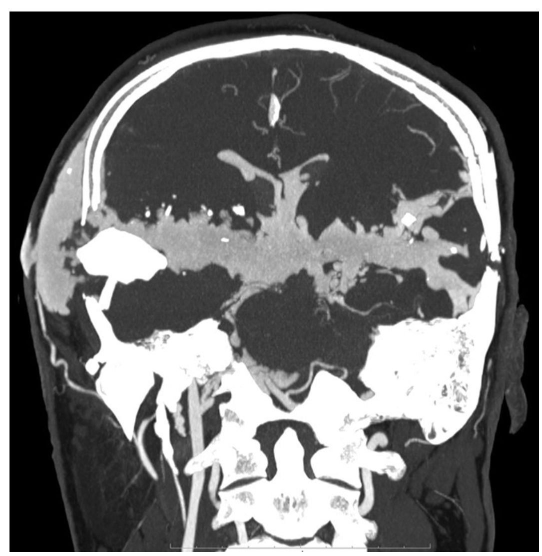

Fig. 6 Thick MIP reconstruction in coronal plane based on PMCTA at the arterial phase: the path of the projectile in a case of the immediate vicinity gun shot (perforating from the *right* to the *left*) shown by broken bones (with bevelling) and extravasation of contrast medium

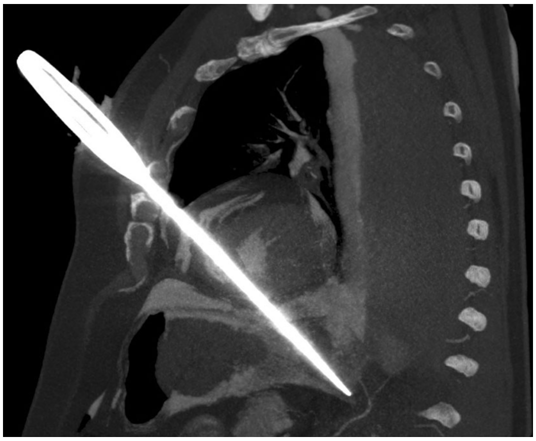

Fig. 7 Thick MIP reconstruction in oblique sagittal plane based on the PMCTA at the dynamic phase: the knife *left* inside the body, perforating the heart and the stomach; contrast medium extravasation to the pleural cavity

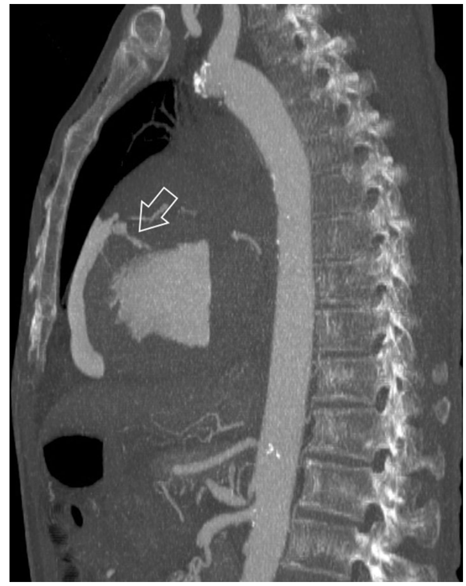

Fig. 8 Thick MIP reconstruction in sagittal plane based on PMCTA at the arterial phase: the injury of the wall of the left ventricle of the heart (*arrow*) with contrast medium extravasation to the pericardial sac

Fig. 9 Thick MIP reconstruction in oblique coronal plane based on PMCTA at the arterial phase: the injury canal due to stab wound of the chest at the *right side* of thorax, leading to the aortic arch, contrast medium leakage to the superior vena cava

[33, 34] as well as case reports [35–37]. Flach et al. [38] reported a case in which the native PMCT combined with the conventional autopsy examination enabled them to indicate the shot sequence in three firearm injuries. A research paper was presented referring to the problem of distinguishing between ferromagnetic and non-ferromagnetic projectiles, which could be an important step in the preparation of the corpse for PMMR examination in projectile injury cases by native PMCT examination [39].

Sharp trauma cases

In general, sharp trauma cases can be even more complicated than ballistic trauma cases—due to the parameters of injuries inflicted mainly by knives. In a number of cases, external injuries can be visible in native PMCT due to air bubbles or blood; using PMCTA can add the focal leakage of the contrast medium. In some cases, the weapon of crime can be left inside the body (Fig. 7) [40], or even a small piece of the weapon (e.g. the blade of the knife) [41, 42] can be found, giving the opportunity to match the recovered foreign body with the rest of the weapon. For the estimation of the injury track, we can utilise the presence of air spaces, gas bubbles, blood and bone/cartilage injuries from a native PMCT examination. Our possibilities can be considerably expanded with the results of PMCTA, from which we can obtain the injury canal of internal organs (Fig. 8) as well as show the location of injuries of vessels [arteries and veins (Fig. 9)] [43]. Unfortunately, in cases with multiple stab injuries, they can overlap their injury tracks. In cases with pulmonary injuries Germerott et al. [44] used post-mortem ventilation (VPMCT) for better visualisation. Among published papers, we can find feasibility studies [45] and case reports [46–48]. There are also published research works referring to the direct contrast filling of injuries [49, 50].

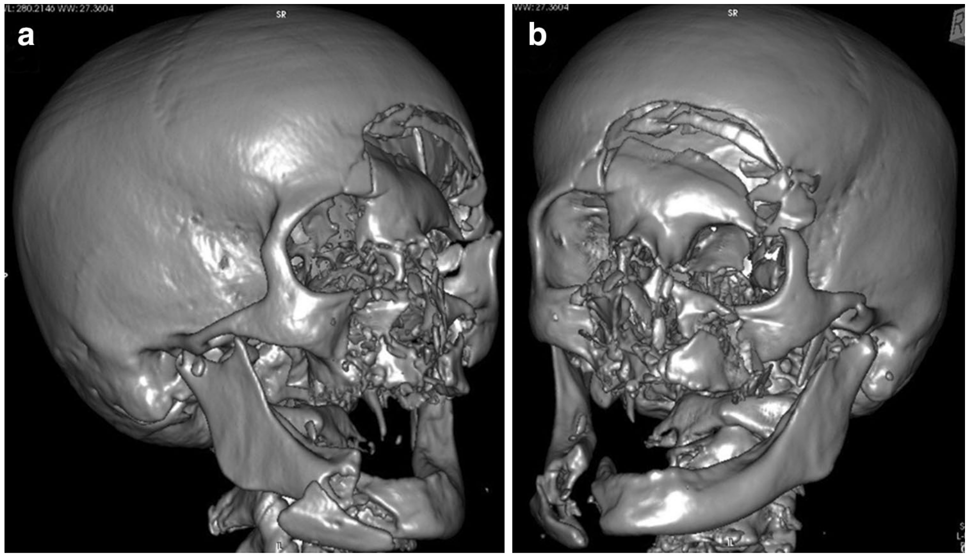

Fig. 10 VRT reconstruction based on native PMCT of a victim of homicide due to blunt trauma to the head: **a** *right* anterior view, **b** *left* anterior view; multiple fractures of the anterior part of the skull

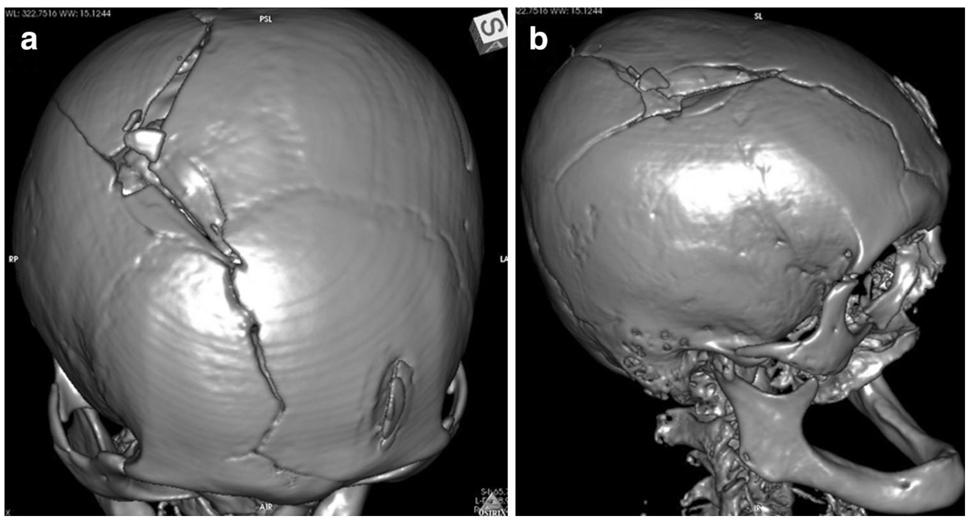

Fig. 11 VRT reconstruction based on native PMCT of a victim of homicide with injuries due to an axe: **a** superior anterior view, **b** *right* (slightly superior) view; multiple fractures of the facial part of the skull, injuries due to the blade of the axe

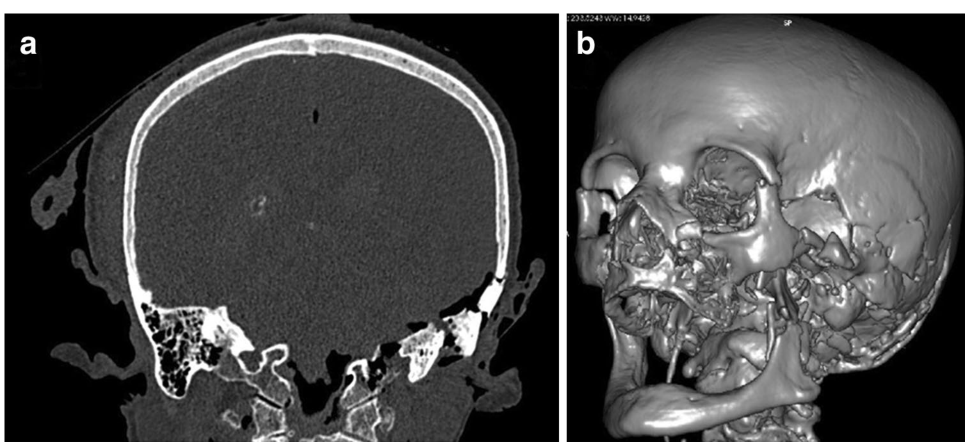

Fig. 12 Reconstructions based on native PMCT of a victim of homicide, showing multiple fractures due to numerous blunt traumas to the skull: **a** thin MIP reconstruction in coronal plane—multiple fractures at the base of the skull on the *left* side, gas inside the skull, **b** VRT reconstruction left anterior view—multiple fractures with small pieces of broken bones (due to iterative trauma to the region)

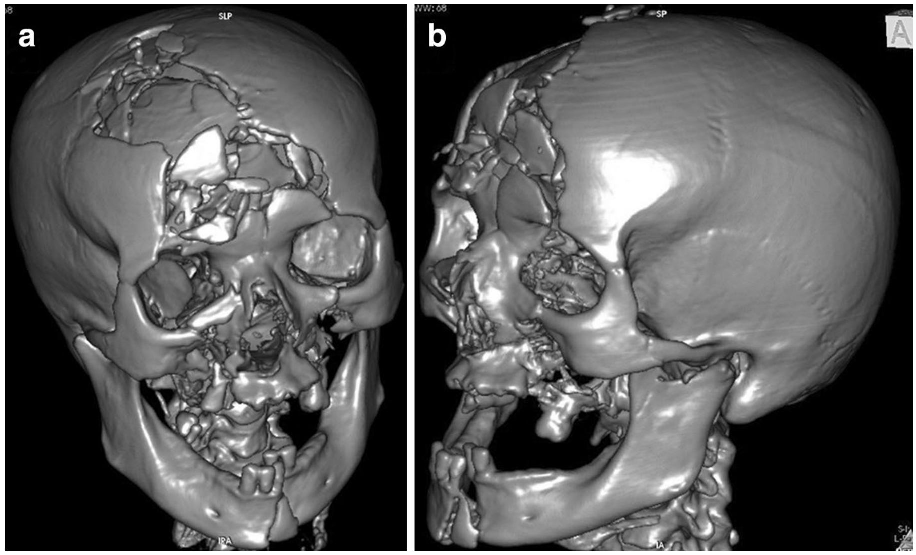

Fig. 13 VRT reconstruction based on native PMCT of a victim of homicide due to blunt trauma to the head: **a** anterior (slightly *right* superior) view, **b** *left* anterior (slightly superior) view; multiple fractures of the skull

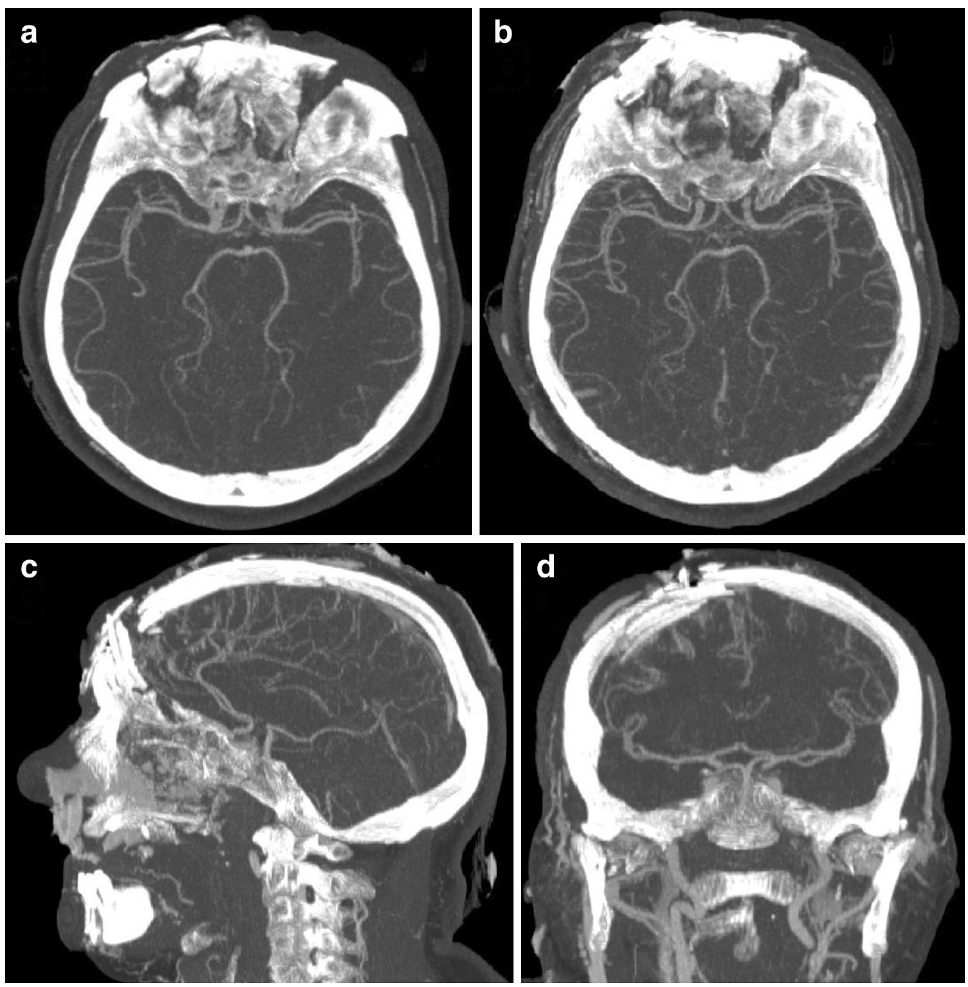

Fig. 14 Thick MIP reconstructions based on the PMCTA of the victim of homicide from Fig. 13: **a** at the arterial phase in axial plane, **b**–**d** at the dynamic phase in (**b**) axial plane, (**c**) sagittal plane, (**d**) coronal plane: multiple fractures of the anterior (and superior) part of the skull, massive contrast medium extravasation at the facial part of the skull, no significant extravasations to the brain

Blunt trauma cases

As mentioned above, the same opportunities and limitations are related to the victims of homicide due to blunt trauma. The native PMCT examination enables us to make a thorough assessment of bone fractures [with 3D visualisation (Figs. 10, 11, 12, 13)] as well as gas/fluid spaces. Ampanozi et al. [51] presented a paper referring to the virtual estimation of free abdominal blood volume. As in the groups of cases discussed earlier, PMCTA can give us the opportunity to widen our findings regarding internal organs and blood vessel injuries (Fig. 14a–d).

There are publications referring to the value of both PMCT and PMMR examinations in blunt trauma cases [52] and the feasibility of PMCT in rib fractures [53]. The head is among the most important regions of the body with regard to the results of blunt trauma [54, 55]. It is recommended to bear in mind the differences between clinical CT examination and PMCT. Persson et al. [56] outlined the problem of a pitfall in the evaluation of post-mortem computed tomography: atlantoaxial rotatory subluxation.

Injury reconstruction with weapon identification as more general research [57], as well as case report papers, was presented [58]. It is important to mention that in some situations, even the data obtained from clinical (ante-mortem) CT acquisition can be highly valuable for forensic reconstructive opinion [59, 60].

Other homicidal cases

There are publications referring to the findings based on native PMCT in strangulation cases, referring to hyoid bone and cartilages of the larynx [61, 62]. In cases of neonaticide, the results of evaluation of native PMCT are reported as diagnostic for the proof of live birth [63], and for decomposed bodies—recognised as superior in the estimation of gestational age [64].

The value of post-mortem imaging (PMCT) is reported in cases of decomposed bodies [65, 66], but even in such cases it is possible to perform successful PMCTA [67].

Even in cases of death related to poisoning (which can also be potentially homicidal), the changes are reported [68]. There is a publication referring to the estimation of time of death based on virtual forensic entomology (micro-CT examination) [69].

Conclusions

As shown above, post-mortem cross-sectional imaging (in the form of PMCT) has an important role in forensic evaluation of homicidal cases. As presented, the relevant application of imaging techniques varies depending on the case, from simple documentation of body state to complex multidisciplinary analysis. In some cases, information obtained from imaging methods can be crucial for the final forensic opinion; these methods should be considered as a gold standard (together with conventional autopsy procedures), at least in all cases where suspicion of homicide is present.

It appears that placing imaging as competitive to conventional autopsy belongs to the past. Understanding the fact that PMCT examination prior to autopsy should simply be a routine order of investigation and can be increasingly widespread not only among the professionals, but also among financing authorities as well. With such an attitude towards post-mortem imaging, including PMCT, standardising its reporting will become an important goal [70].

Acknowledgments Author's PMCTA research approved by the Jagiellonian University Bioethics Committee (KBET/225/B/2012).

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

Ethical standards This article does not contain any studies with human participants or animals performed by any of the authors.

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