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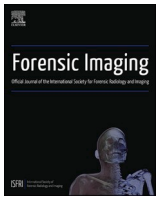

Review article

Post-mortem imaging: A tool to improve post-mortem analysis and case management during terrorist attacks

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ABSTRACT

Terrorism is a global issue and a constant international threat.

Post-mortem imaging through post-mortem computed tomography (PMCT) techniques entered the panorama of methods used for forensic investigations, and are largely applied worldwide. In particular, since they can show the skeletal system and major parenchymal alterations and aid the localization of foreign bodies, they have been already applied in disasters related to terrorism attack, for identification of the victims, the documentation of injuries, and reconstruction of the event.

The aim of this paper is to explore the potentials of PMCT methods in forensic investigations related to terrorism attack.

1. Introduction

Terrorism is an age-old plague. The incidence of terrorist attacks and the number of casualties constantly on the rise, along with the ever-expanding harm it brings to people around the world is forcing the world to push knowledge over new boundaries.

This has led to the introduction of new investigative modalities and integrating existing technologies and methods or using them in an innovative way to face such emergency situations.

In the context of a terrorist attack, forensic science covers a fundamental role in addressing the issues related to the investigative process.

Because of the complexity of these issues, the forensic analysis of terrorism victims requires a comprehensive approach.

Post-mortem investigation on the victims and circumstances of a terrorist attack requires huge efforts to the forensic community and prompt the immediate and rapid intervention of experts with different backgrounds using their skills for rapidly reaching appropriate forensic conclusions.

Post-mortem imaging, specifically post-mortem computed tomography (PMCT), has been already used for enhancing forensic investigations in the aftermath of terrorist attacks [1–5].

In the particular context, the authors propose modern techniques using virtual autopsy by PMCT for enhancing the forensic analysis on the victims and circumstances of terrorist disasters [6,7].

2. Virtual autopsy and its role in terrorist attack

Virtual autopsy, a term first used by Thali, consists in the application of radiological techniques to post-mortem investigations to obtain a non/low-invasive autopsy [8–10]. Many different techniques have been successfully applied in post-mortem investigations, that are CT [11–18], even with pulmonary ventilation [19], MRI, photogrammetry and 3D surface scanning, PMCT angiography and percutaneous post-mortem biopsy (eventually under CT guide for tissue or body fluid sampling) [20–22]. However, nowadays post-mortem computed tomography (PMCT) is the most used imaging technique in forensic practice [6]. Even, PMCT has been applied as a substitute to classical autopsy in selected cases [16,23,24].

PMCT offers an excellent assessment of the body, or body parts, even when severely damaged, and a precise localization of foreign materials

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(projectiles, part of them, explosive materials, medical devices, personal belongings, environmental material) [6]. This documentation is useful in the pre-autopsy stage of investigation, as general overview of the case. It can provide huge data rapidly after the event, that might be crucial for the investigators at the crime scene. Huge information about the terrorist attack can be obtained before autopsy, particularly if we consider that mobile CT scanners can be used onsite [25]. This potential can be particularly useful not only for the investigative process, but also for the safety of the operators involved in the analysis. PMCT digital documentation, moreover, can be permanently archived and re-examined by different experts, if further issues or queries arise after autopsy, needing to be clarified.

Due to these advantageous characteristics, PMCT a been already proposed as a valuable investigative method for mass fatalities [26]. This is truer also if we consider that PMCT is applicable not only to humans, even in natural deaths [27], but also to animals [28,29] and environmental material, that renders these techniques very useful during terrorist attack investigations.

According to the members of the Disaster Victim Identification working group of the International Society of Forensic Radiology and Imaging, who proposed in July 2019 [26] their position statement, the use of PMCT was recommended, for disaster victim identification, the description and documentation of the nature of wounds, the determination of the cause of death or contributing cause of death, providing proofs regarding the source and circumstances of the disaster, thus gathering evidence for criminal justice procedures. In addition, more properly than classical techniques, PMCT has been proposed also for identifying potential hazardous materials within the body, that classical techniques in general fail to quickly demonstrate.

In this paper, we speculate on the potentials of the modern techniques of virtual autopsy by PMCT as a viable non-invasive, or minimally invasive technique for analysis of the victims of a terrorist attack and for forensic investigative process in this kind of mass casualties. The role of PMCT in assessing the major issues of forensic investigations during terrorist attack will be discussed. Especially, the potentials of PMCT in the identification process, in the description of body lesions caused by firearms and explosions will be examined.

2.1. Virtual autopsy and disaster victim identification

The identification of the victims covers a crucial part of forensic pathologists' tasks during a terrorist attack. Identification is made through the definition of age and sex, and when present more specific characteristics of the individuals such as unique biological or physical features, identifying a single subject.

Identification of the victims of these events is considered an important mark of respect also for surviving family and friends. In addition, identification may be required for legal reasons, for example to aid criminal proceedings, facilitate establishment of estate and/or inheritance, or the right of the remaining partner to re-marry. Consequently, specific processes and protocols have been developed to reach identification of the deceased [30].

Various forensic specialists are involved in DVI including the forensic pathologists, forensic odontologists, forensic radiologists, molecular biologists, forensic radiologists, and relatively recently, the forensic anthropologists [31–37].

The identification process of an unknown individual comprises various techniques that are visual inspection, fingerprinting, dental and DNA analysis. PMCT is nowadays a regularly accepted method for identification [34,38], especially when traditional techniques are not possible, or too time consuming.

Conventional radiography has been classically used to assess the bony skeleton and to detect radio-opaque materials (for example bone or dental implants) [39]. However, PMCT offers undisputable advantages with respect to conventional radiography, due to its spatial resolution and the possibility to exactly describe and localize bones and implants, useful for identification.

Especially, in cases of terrorist attack the integrity of the body of the victims is often not respected, and PMCT techniques can easily and rapidly individuate and isolate body parts and bones and implants and differentiate it by foreign material.

Moreover, with post-processing techniques, with 2D and 3D reconstruction and dental reconstructions PMCT imaging (Fig. 1) as a unique technique is able to provide a 2D and 3D dataset comparable to antemortem images (including traditional orthopantomograms) for identification, minimizing the number of imaging modalities required for the identification process [34].

These characteristics of PMCT analysis for identification are able to speed enormously the entire process, that is an important task during a terrorist attack.

2.2. Virtual autopsy and documentation of firearm injuries

One of the most common types of weapons used by terrorists are gunshots. As illustrated in the paper by Oliva et al. [1], gunshots of variable types can be used, depending on the velocity of the shot, that causes different types of lesions.

Moreover, high velocity shot guns are the most frequently employed because of the higher capacity to cause injury such as fragmentation of the bones and disintegration of the organs that are not particularly elastic (like the liver and spleen) [40–42]. In addition, firearms are usually loaded with bullets settled to maximize the damage they can inflict.

One of the most explored and old fields of application of post-mortem forensic radiology is represented by gunshot injuries [43]. The cause is the ability of PMCT to identify bullets or fragments of the bullets, and to depict easily and quickly the exact position in the three dimensions of these kind foreign bodies and bone fragments and bone lesion. This render PMCT particularly valuable technique in the study of cranio-encephalic district, that is justified by the particular anatomic conformation of this region [44]. PMCT is able to precisely describe bone defect through the cranium and thus it provides a description of the entry hole and eventual exit hole. Moreover, through the description of the dispersion of bullet and bone fragments and parenchymal lesions, such as hemorrhage and gas bubbles, PMCT can aid to the definition of the intracorporeal trajectory of the bullet especially in the cranio-encephalic district [44].

Moreover, PMCT imaging permits the detection and exact localization of foreign bodies such as bullets or fragments of them, even when they were hidden in areas that are not usually dissected during an autopsy, that are the face, limbs and paravertebral soft tissues (Fig. 2). By doing so, PMCT images analysis can facilitate autopsy, and can reduce the length of incisions made during the autopsy in areas like the face, whose integrity should always be preserved, whenever possible, for the benefit of the victim's relatives. Furthermore, the retrieving and extraction of all bullets or parts of them is crucial for gaining information about the ammunition and firearms used, that are fundamental to the investigations of counterterrorism agencies.

2.3. Virtual autopsy and documentation of explosives injuries

Explosives are a frequent destructive instrument used by terrorists [1]. Improvised explosives such as pipe bombs are usually filled by terrorists with glass fragments and metallic spheres. Death by such explosives can be caused by blast waves, with perforation of gas-filled organs, e.g., the lungs and bowels, fragment penetration/blunt traumas, building collapse, and trauma resulting from body transposition [45–48].

The predominant post explosion injuries are related to penetrating and blunt trauma (Fig. 3). Moreover, heat lesions and carbonization should also be considered.

However, during an explosion a violent and sudden fluid expansion

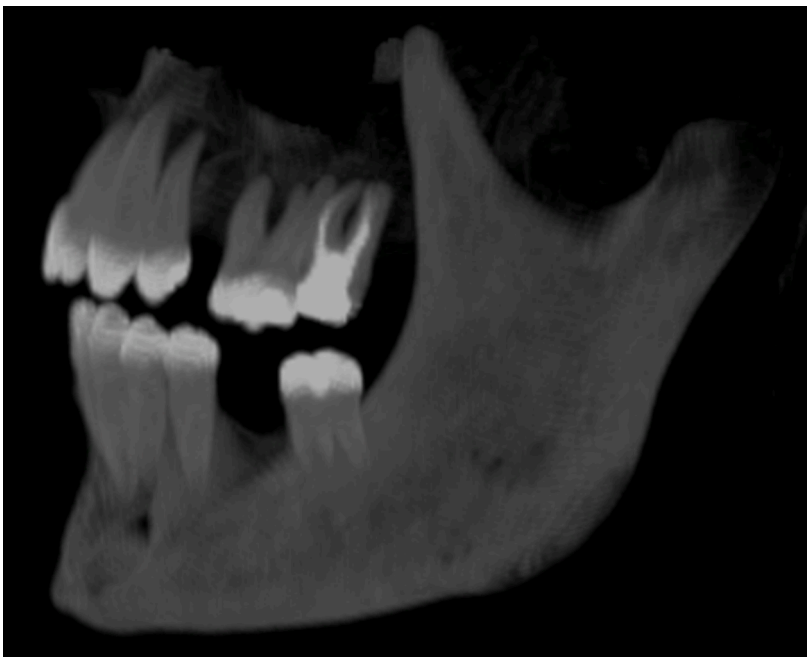

Fig. 1. Maximum intensity projection reconstruction of the left emimandible in a victim of terrorist attack with severely damaged maxillo-facial region.

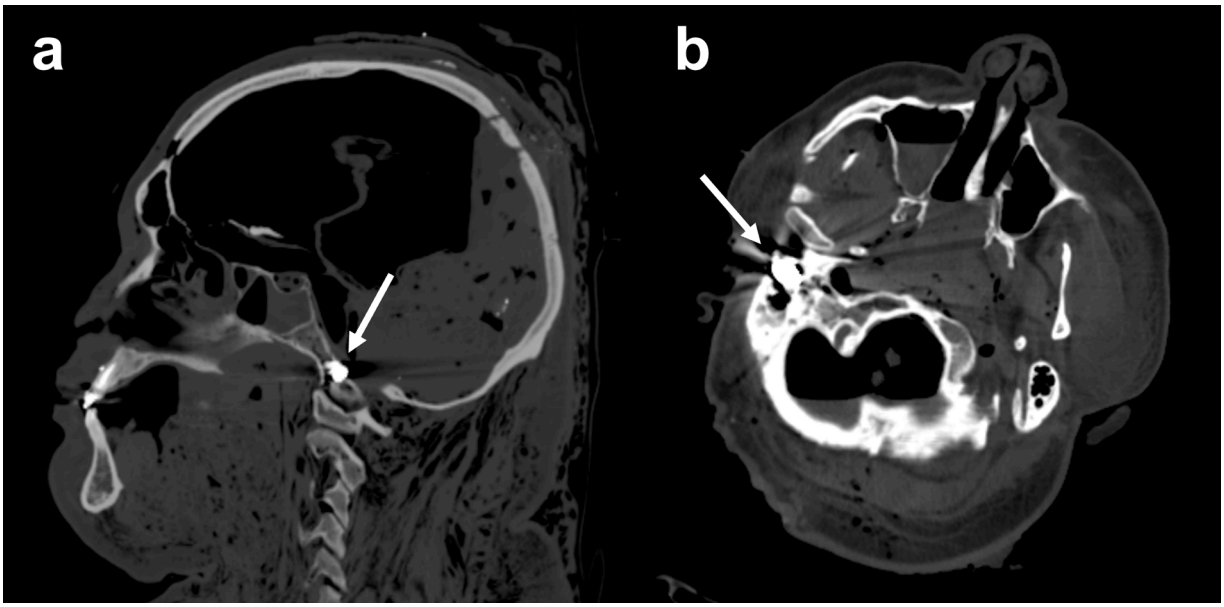

Fig. 2. a–b 2D MPR reconstructions of the head. The images show a fragmented bullet in the clivus (a) and in the petrous part of the temporal bone (b) (arrows).

causes a rapid and huge rise of pressure in the existing space [48]. This great movement of air (or water) masses determines a rapid succession of compressive and decompressive waves [48]. The pattern of injuries is defined by environment, the distance between the victim etc. as well as by the amount and composition of explosive material, and the type of explosive device [48]. However, barotrauma and consequently blast injuries represent the major mechanism of wounding and mortality [48]. In fact, he main mechanism of injury and mortality in explosion-related deaths is due to the interaction between the shock waves generated in the explosion and the gases in the lungs and viscera, generating a barotrauma. While the lungs are frequently hyperinflated, the trachea and major bronchi may exhibit lacerations or rupture due to rib fractures. The same effects of barotrauma such as hemorrhagic injuries, avulsions, or lacerations, can also occur in the digestive system.

Gas-containing sections of the gastro-intestinal tract are most vulnerable to blast effect. Bowel perforation, hemorrhage, mesenteric shear injuries, solid organ lacerations, and testicular rupture can be a consequence [48].

Due to its capacity to identify significant skeletal and parenchymal lesions, PMCT stands out as an indispensable resource when it comes to giving a repeatable iconographic picture of the various fracture complexes.

The PMCT imaging examination is an essential investigative tool in trauma due to its extensive analysis of anatomical parts, including the pelvis, spine, and limbs that are challenging to assess with a classical autopsy dissection [1].

Moreover, by identifying even tiny metal particles that are a part of the explosive device PMCT could be extremely helpful in enabling the

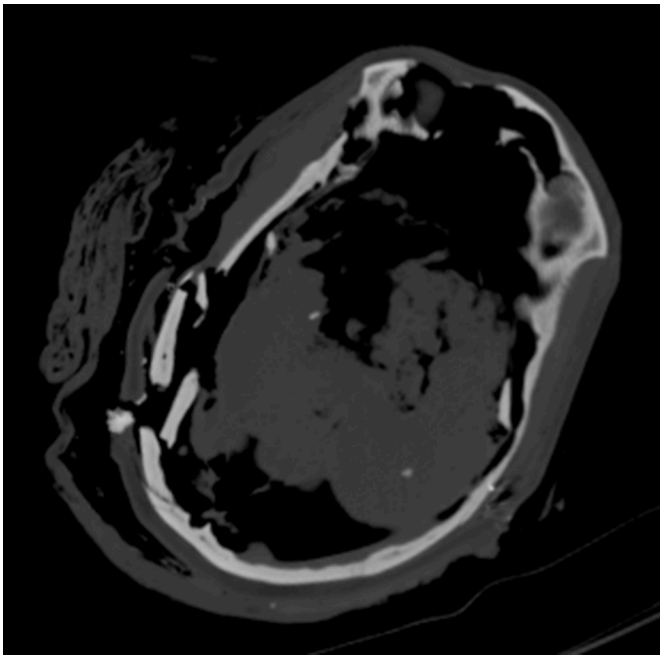

Fig. 3. 2D MPR reconstruction of the head. The image shows multiple, partially depressed fractures of the cranium in a victim of terrorist attack.

ballistics experts to identify the work of a certain bomb-maker or terrorist organization [1].

3. Conclusions

Due to the well-recognized advantages of PMCT in the investigations on terrorism attack, these imaging techniques are largely recommended in this kind of disasters.

Thanks to the potentials of PMCT in identification process and documentation of injuries and reconstruction of the event, the role of autopsy has largely been reduced. Even, O'Donnell et al. [34] have suggested that autopsy examination might be "limited to the clarification of CT findings and minor dissection for the purposes of determining cause and manner of death".

We completely agree with this suggestion.

It is clear that this kind of post-mortem investigation requires considerable planning and resources, and qualified experts are essential for a proper and better utilization of these methods and a real exploitation of their potentials.

However, we are convinced that PMCT methods represent an unreplaceable instrument during terrorist attack investigation, and that it should enter in the investigation process as an integral part of formal protocol during investigations on terrorist attack.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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