

Postmortem computed tomography (PMCT) and disaster victim identification

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Abstract Radiography has been used for identification since 1927, and established a role in mass fatality investigations in 1949. More recently, postmortem computed tomography (PMCT) has been used for disaster victim identification (DVI). PMCT offers several advantages compared with fluoroscopy, plain film and dental X-rays, including: speed, reducing the number of on-site personnel and imaging modalities required, making it potentially more efficient. However, there are limitations that inhibit the international adoption of PMCT into routine practice. One particular problem is that due to the fact that forensic radiology is a relatively new sub-speciality, there are no internationally established standards for image acquisition, image interpretation and archiving. This is reflected by the current INTERPOL DVI form, which does not contain a PMCT section. The DVI working group of the International Society of Forensic Radiology and Imaging supports the use of imaging in mass fatality response and has published positional statements in this area. This review will discuss forensic radiology, PMCT, and its role in disaster victim identification.

Keywords Disaster victim identification (DVI) · Mass fatality incident (MFI) · Postmortem computed tomography (PMCT) · Imaging

Introduction

Radiology was first reported for the purpose of human identification by Culbert and Law in 1927, when investigators compared antemortem and postmortem radiographs of the frontal sinus of a homicide victim [1]. By comparing the unique biological features of nasal accessory and mastoid sinuses, visible on both sets of X-rays, the doctors were able to confirm that the deceased man was formerly their patient. This comparison of ante and postmortem radiographs is still considered to be one of the most accurate techniques to establish identity.

Radiology subsequently established a role in mass fatality examinations in 1949, when it was used to help identify the victims of the Great Lakes liner “Noronic” disaster in Toronto, Canada. The fire that destroyed the Noronic ship resulted in 119 fatalities. Plain film radiographs were taken of 79 of the 199 fatalities, and corresponding antemortem radiographs were obtained for 35 of these cases, providing an eventual positive identification in 24 of the most severely disfigured cases by radiology alone [2]. In many of the other cases, the radiographs provided supporting evidence for, or exclusion of, the identification suggestions produced by other techniques. Due to acute disruption of the casualties, antemortem fractures were not of much evidentiary value, but congenital abnormalities and chronic conditions were of great value in several instances. Four of the individuals were identified by abnormalities of the spinal column, seven by arthritis of the spine, one from arthritis of the knee and one by arthritis of the calcaneus, all of which were distinctive enough on radiographs to produce positive identifications.

Since then, the role of radiology in human identification and mass fatality examination has developed enormously. Technological advances, including the development of computed tomography (CT) and magnetic resonance

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imaging (MRI), in combination with training and education have helped to unlock the true evidentiary value of these technologies for forensic investigations. Radiology and forensic departments now work closely together, so much so that forensic radiology is considered a new sub-speciality in its own right and is a key component in any multidisciplinary team dealing with casualty identification [3].

Disaster victim identification (DVI)

An incident is classified as a mass fatality incident (MFI) when it involves five or more casualties and is sub-divided into: major, mass or catastrophic, depending on the total quantity of victims. An MFI may be local, national or, more commonly these days, international based on the location of the incident and the country/countries of origin of the victims. They may also be closed or open incidents, depending on whether the number of casualties is known, and whether the identities of the group involved are known. For example, an aircraft-related incident is normally a ‘closed’ incident, as there is a manifestation of those travelling on the plane, whilst in contrast the attacks on the World Trade Centres in New York in 2001, and the Asian tsunami in 2004, represent two of the most complex ‘open’ MFIs to date, with the precise number of victims still unknown.

MFI can be further categorized as environmental (e.g. earthquakes, tsunamis, hurricanes), medical (e.g. famine, disease; such as the 2014 Ebola outbreak), vehicle (e.g. aircraft, car, train, ship), industrial (e.g. explosions, fires) or terrorist (e.g. chemical, biological, radiological, nuclear or explosive attacks, i.e. so-called CBRNE). Human rights (HR) violations may also be considered to be mass disasters; although they may occur over a larger geographical area and time [4]. These categories are important when planning the site and type of mortuary to be utilized, e.g. a permanent site, temporary or CBRN mortuary.

For an MFI, victim identification is of primary importance, as investigators have a humanitarian and legal responsibility to identify each casualty, where possible, so that they can be returned to their next of kin [5]. This is generally achieved by following disaster victim identification (DVI) protocols. Incident-specific variables will directly influence the selection of victim identification methods employed [6]. For example, aircraft and industrial incidents, terrorist attacks and natural disasters often present fragmentation, heat damage and commingling problems, which require a more extensive mortuary setup.

The complexity of victim identification in the aftermath of an MFI can vary tremendously and depends on the context, number of fatalities, extent of body fragmentation, decay and the availability of antemortem reference material related to missing individuals. To ensure that bodies

are identified as quickly and efficiently as possible, a multidisciplinary team is generally deployed to work simultaneously to increase the productivity of the identification process. This usually consists of police, pathology and odontology personnel, although with the recent trend in the use of PMCT the radiologist is also becoming an integral part of the mortuary identification team.

Disaster victim identification (DVI) capability and standards are required to cover international as well as national incidents. To date, the International Police Organization’s (Interpol) resolution on DVI is the only internationally recognized legislation, which functions under international law, to specifically address this issue. They recommend that all 187-member countries should adopt a common procedure for identifying victims in any type of disaster, regardless of its cause or scale [7].

In 1984, Interpol published the first DVI manual. Their aim was to provide information relating to mass disaster handling in general, and the identification process in particular, to increase the efficiency and effectiveness of DVI [7]. To achieve, maintain and improve standards, and to facilitate international liaison, Interpol recommends that each member country establish one or more permanent disaster victim identification teams. They should have a responsibility not only for disaster response, but also for the vital functions of pre-planning and training of key personnel. The Interpol DVI guide (<http://www.interpol.int/INTERPOL-expertise/Forensics/DVI-Pages/DVIguide>) assumes that postmortem intervention will be organized and describes the DVI process including three key steps. These are recovery and examination of bodies to establish postmortem evidence from the deceased, search for antemortem information for possible victims and the reconciliation of antemortem and postmortem data [8].

The Interpol guidebook contains two separate specific forms for recording the antemortem (AM) and postmortem (PM) information, to assist the identification process [5]. The AM team collects data of suspected victims, prepares corresponding missing persons files and notifies the relevant authorities regarding successful identifications. The PM team collects all relevant dental, medical and forensic data from the deceased bodies for the purpose of identification of victims. The AM and PM data are then processed by the reconciliation team, which attempts to match the information collected by both teams and identify the victims. The result of the PM/AM comparison is not always conclusive and therefore a match may render the following outcomes [9, 10]:

- *Identification completed* Certainty that PM and AM data originated most definitely from the same individual.
- *Identification probable* Specific characteristics match, but either PM or AM data are insufficient to draw the conclusion with certainty.

- *Identification possible* Nothing that excludes the identity of the victim based on the comparison of PM or AM data; both sets are minimal.
- *Identity excluded* Certainty that PM and AM data sets are both too minimal to be conclusive.

As well as comparative identification, reconstructive identifications can also be achieved by matching a set of PM classification criteria to a large population of AM data to narrow the number of possible identities. The most simple and practical categories are sex (male/female) and age (child/adult). More differentiating criteria, such as stature and race, are typically more directly affected by mutilation and/or decomposition. After the initial examination to determine sex and age, the bodies will be screened against a list of more distinguishing features (e.g. medical implants, dental abnormalities/restorations, scars, tattoos).

Ultimately, the successful identification of individuals involved in a mass fatality incident is dependent on the availability and quality of antemortem information for each victim [11]. Interpol categorizes this information into circumstantial and physical evidence. Circumstantial evidence relates to personal effects, such as clothing, jewellery and pocket contents [12], and cannot be used alone as proof of identity. Physical evidence is acquired through external or internal examination of the body and is considered as admissible evidence [12]. External examination may reveal individuating characteristics such as tattoos, scars and fingerprints, which can be extremely useful when confirming identity [13]. Likewise, internal examination may expose evidence of surgical procedures, including natural disease, prosthetics or evidence of previous trauma; all of which may be exclusive to the individual [13]. INTERPOL has prescribed these rigorous standards for gathering and recording of information, due to the importance of this physical evidence to achieve a positive identification.

Forensic imaging and DVI

PMCT was first reported for a drowning death after a diving accident in 1983 [14]. This report was followed by many other similar publications and even several books dedicated to forensic imaging [15–22]. Also known as a ‘virtual autopsy’, the concept of postmortem imaging developed its roots in Israel in 1994 when it was first proposed that PMCT could replace the need for an autopsy [23].

In 2002, the Virtopsy[®] group was established at the Institute of Legal Medicine, University of Berne, Switzerland. This group [24], along with several other research groups [21, 25–27], considered the possibility of using PMCT to establish minimally invasive routine imaging methods in forensic pathology to supplement, or even replace,

traditional autopsies. These research groups are continually producing scientific data to support the introduction of PMCT into the mortuary.

The current standard approach, as used in previous incidents such as the terrorist bombings in London in 2005, involves moving fatalities through three separate radiological stations: fluoroscopy, to screen for potential contaminants or evidence prior to autopsy; standard radiography, principally used for anthropological and pathological examination; and dental radiography, for dental identification. This process requires the procurement and insulation of three different imaging modalities in a temporary mortuary, sufficient staff to operate them and subsequently a number of health and safety implications. For example, mobile fluoroscopy units require the operator to be positioned next to the body throughout the imaging process, to capture images when necessary as they move the machinery systematically along the length of the body. They may also need to open the body bag and manipulate the remains to obtain a good imaging plane, exposing them to potential contamination and often disturbing sights. This surface investigation takes approximately 15 min and pathologists are normally responsible for interpreting and reporting the resulting radiological images, although they are often not specifically trained to do this. As with fluoroscopy, plain film radiograph stations require a separate team of operators and the body bags may also need to be opened to optimize the imaging procedure. The radiographs are normally examined by either radiographers or forensic pathologists and communicated verbally. This means a formal radiological report is often not generated, which can be an issue if the case needs to be reviewed again at a later date. Dental X-rays are generally undertaken by an odontology team, rather than a radiography team [28]. They face similar issues regarding body manipulation, contamination and staffing. In addition, all of these imaging modalities normally need their own specific electrical power supply and a dry working environment, which presents a number of logistical problems in a temporary mortuary.

Using PMCT has the potential to replace these three independent modalities, and therefore could improve issues relating to equipment sourcing, operational personnel and health and safety. PMCT is an extremely useful investigative tool in a mass fatality incident, particularly for the purpose of disaster victim identification. The rapid and accurate identification of individuals is of primary importance for both judicial reasons and for relatives’ peace of mind. Since the first radiologic identification nearly 90 years ago, radiology has been a key component in the identification process by comparing postmortem and antemortem information, on the assumption that each individual exhibits unique features [29]. It has also been used to provide valuable supplementary information to help with the detection of

foreign bodies that may pose a hazard to on-site investigators, to uncover and pinpoint the exact location of material evidence and provide an image inventory of all recovered body parts that can be stored indefinitely (for future reference) and transferred easily to remote professionals.

Transporting bodies to clinical CT scanners following an MFI is possible, but can often create a number of logistical issues, particularly if the incident occurs in a remote area, a country that does not routinely use CT in general practice, or the disaster is so catastrophic that the medical infrastructure of the country is drastically affected. This led to Ruty suggesting at numerous meetings in the United Kingdom (UK) around 2004 that a truck-based mobile CT scanner could be deployed to the scene of an incident or temporary mortuary, instead of using clinical scanners as a potential solution to these logistical issues. Ruty also identified that mobile PMCT would be particularly valuable when dealing with mass fatality events involving chemical, biological, radiological or nuclear materials (CBRN). These types of incidents require particular procedures and specialist equipment to minimize the potential contamination.

The use of mobile PMCT scanners in a forensic setting was first reported in Japan [30]. Two years later in February 2006, Ruty and colleagues were the first group to implement the use of a mobile CT scanner in a small MFI [21]. As a result of this experience, this research group later developed a tele-radiology system for remote data reporting in MFIs, which they termed the FiMAG system [26]. This system allows secure global distribution of PMCT scans and international evaluation of images for identification purposes in a DVI event. The FiMAG system was primarily implemented by the authors to address the risks involved with a contaminated mass fatality scene and provided a remote radiological diagnostic service. A mobile CT scanner was deployed at the European Union-funded, multi-national CBRN and conventional mortuary exercise, Operation Torch in 2008, and the FiMag system was internationally tested during Operation Hounslow in 2011. During this operation, an on-site radiology team was able to report on the scans as they were being taken and the information was fed directly into the mortuary, either as a hard copy or live monitor feed into the DVI examination area. PMCT data were also sent to reporting teams in Europe, Scandinavia, Japan, Australia and South America.

Operation torch has been one of the only large-scale DVI simulation exercises to consider appropriate image reporting, secure data transfer and storage, an area that has previously received little attention. Data were sent to remote investigators by transferring the data onto a secure online database using a unique data entry code for each body or body part. The data entry code was based on the national identification number system presented with the remains on the Association of Chief Police Officers

(ACPO) or Interpol Victim Profile Form (VPF). An on-site support DICOM server acted as a hub for data transfer and field reporting workstation. Encrypted raw DICOM data were then sent from this hub via telephone line, 3G or satellite network using a virtual private network (VPN) to the forensic picture archiving system (FPACS) image router and web server. Access to the VPF was then made available at remote reporting locations anywhere in the world. This method of secure data transfer should be used to maintain stringent judicial requirements.

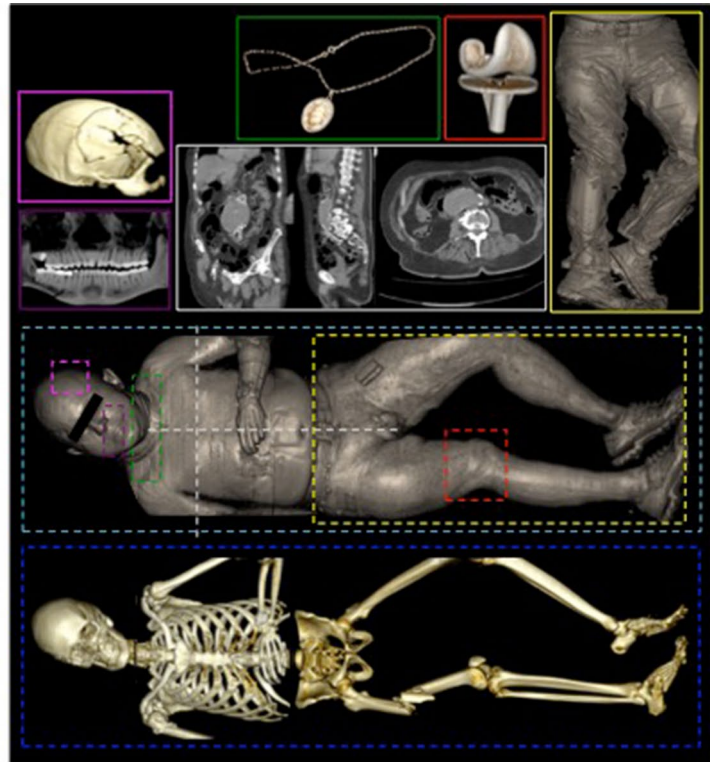
Outside the UK, the Virtopsy[®] group has considered the benefits of mobile PMCT as a mass fatality-screening tool and researched its ability to collect information to complete the Interpol DVI forms [31, 32]. They have also suggested the use of robotic tissue sampling in association with PMCT in contaminated mass fatalities [32, 33]. PMCT played an integral role in the DVI of victims of the Victorian Bush Fires, Australia [22, 34, 35], and has been used in modern military conflict areas for the examination of projectile-related injuries as well as vehicle- and air-related incidents.

Potential role of PMCT in DVI

The current official DVI Interpol form does not contain a specific PMCT section, let alone a radiology part. However, on inspection of this form, it appears that the substantive parts of information required could potentially be extracted from PMCT data (Fig. 1). This being said, some information would still need to be collected manually, such as an external inspection of the body and the removal of personal items, as PMCT cannot clearly define words on labels, the inscriptions on rings or the natures of inked tattoos due to resolution limitations.

A review of the most regularly used anthropological identification techniques, by Brough et al. [36], demonstrated that all the measurements and morphological features required for these methods can be extracted from PMCT data. In a more recent publication [37], the same authors suggested that it would also be possible to complete the majority of the current DVI Interpol form using only PMCT, an external examination (including recovery and documentation of personal possessions), fingerprints and DNA (Table 1). They demonstrated that an external body description and osteological report of the remains could be conducted from 3D reconstructions. In addition, personal effects, clothing, medical implants/interventions and natural internal disease that has been documented in an individual's medical history can be located for further inspection, using either 3D reconstructions or 2D MPRs without the necessity for an invasive internal examination. Therefore, in terms of ascertaining a cause of death and

Sections PMCT could assist/complete	Sections PMCT could not complete
B (22): State of body	B0: Checklist of operations for mortuary
B (22A): Important ID information	D5 (1-4): Fingerprint information
C (24-25): Clothing and footwear*	E4: DNA information
C2+C3 (26-30): Personal effects*	
D1 (31-55): Physical description ¹	
D4 (described in 22 and or/ 31,53): Body sketch	
E2 (71-75): Medical conclusions ²	
E3: Skeletal inventory	
F1 (83-85): Dental findings	
F2 (86-91): Dental inventory	
G (92): Further information	
E1 (60-65): Internal examination	



¹ (33) Except Weight; ² (73) Except Samples taken;

Fig. 1 A summary of INTERPOL requirements. This figure illustrates the sections of the INTERPOL form that PMCT could assist with. This highlights that PMCT could be used to retrieve the large majority of information required. *Clothing and footwear, Personal

effects; PMCT can identify general items for inventory but for more specific details, e.g. travellers' cheques, type of credit card; a physical examination of the item is required. PMCT could be used to map the exact location of these items for rapid retrieval

Table 1 A summary of INTERPOL requirements

Sections PMCT could assist/complete	Sections PMCT could not complete
B (22): State of body	B0: Checklist of operations for mortuary
B (22A): Important ID information	D5 (1-4): Fingerprint information
C (24-25): Clothing and footwear*	E4: DNA information
C2 + C3 (26-30): Personal effects*	
D1 (31-55): Physical description ^a	
D4 (described in 22 and or/31,53): Body sketch	
E2 (71-75): Medical conclusions ^b	
E3: Skeletal inventory	
F1 (83-85): Dental findings	
F2 (86-91): Dental inventory	
G (92): Further information	
E1 (60-65): Internal examination	

* Clothing and footwear, personal effects; PMCT would be able to identify general items for inventory, but for more specific details, e.g. travellers' cheques and type of credit card, a physical examination of the item would be required. However, in scenarios where the bodies can be scanned in a sealed body bag to minimize contamination exposure, PMCT would be able to map the exact location of these items for rapid retrieval

^a (33) Except weight; ^b (73) Except samples taken

identification of unknown remains in an MFI, PMCT could remove the necessity of an invasive examination.

In addition, PMCT dental reconstructions could be used in the same manner as traditional orthopantomograms (OPTs) for the estimation of age and identification of unique dental features, with the added advantage of producing a 3D dataset as opposed to a single 2D image. Using PMCT for dental identification would also minimize the number of medical imaging modalities required on-site. However, it is important to note that image artefacts can be produced from unremovable metal work or (mercury based) dental amalgam in fillings, which may limit PMCT's evidentiary value, less common in a younger age group. Artefacts include 'beam hardening' where the density of structures are misrepresented by differential attenuation of X-rays by metal, and more significantly 'photon depletion' where the high attenuation by metal reduces the beam intensity so drastically that a diagnostic image cannot be computed in that region, causing streaking and black areas. This can affect the precision of measurements used for various identification techniques, such as age estimation and comparison identifications.

A more extensive investigation on a cellular level is not possible using PMCT. However, in these circumstances, complementary techniques to a "virtual autopsy" approach such as 'image-guided needle biopsy' may be used to provide additional information. This is a minimally invasive diagnostic technique that facilitates the fast and accurate collection of representative samples of organ tissue and body fluids through small punctures and has been around as long as histology [38].

Development of forensic imaging in DVI

In 2012, the DVI sub-group of the International Society for Forensic Radiology and Imaging (ISFRI) released a positional statement outlining the issues facing the field of forensic radiology, which included six key areas of development on which dedicated working groups would focus [39]. This publication recommended that, where possible, a radiological examination should always form part of the DVI process and that the modality used would be dependent on the equipment available at the time and the individual requirements of each DVI scenario. The ISFRI membership suggested that the modalities used should include radiographs (plain film, computed or digital radiography), fluoroscopy, computed tomography or dental radiography, either singularly or in combination. Furthermore, they considered that although MRI has been considered for post-mortem imaging, its utility in DVI events is limited by additional cost, extended scan time and mobility implications and is therefore not considered suitable unless the only antemortem comparison image is MR.

In May 2014, a consensus document written on behalf of the members of ISFRI and supported by the International Association of Forensic Radiographers (IAFR), regarding the use of PMCT in DVI, recommended that it should be used for: (1) identifying the cause of, and contributory factors to, death; (2) disaster victim identification (DVI); (3) identifying potential hazardous materials within the body; (4) gathering evidence for criminal justice procedures [40]. This document also provides a detailed description of recommended body handling, PMCT scan, image data handling and image interpretation procedures. These protocols have been designed by the group to be applicable to both mobile (lorry based) and fixed site CT scanners and therefore include procedures for both at the scene of the incident or within a permanent or temporary mortuary.

PMCT reporting

Over the last decade, the frequency of PMCT scanning has increased rapidly and therefore its role in DVI events has also increased. This presents the important questions of (1) whether PMCT reporting should follow an official structured reporting format, or alternatively whether a free reporting format should be used [41] and, (2) who should be interpreting the data? This might be dictated by legal requirements as set out by law and landmark court decisions. The core task of any postmortem examination of a body is to provide a comprehensive account of all the relevant findings. Therefore, all data gathered, as well as case-relevant significant findings within any of the data (including PMCT data with reports of the presence as well as absence of relevant findings) have to be explicitly reported. Without a structured reporting format in place, the readers of PMCT currently use their judgment in what they want to report and how they want to formulate their written reports. There is also no guidance regarding who should be interpreting the scan data. Should it be a radiologist with knowledge of forensic pathology or a forensic pathologist with knowledge of radiology? Or, should both professions work together to provide a collaborative report of the findings? To ensure that PMCT is considered for the next DVI Interpol update, it is essential to develop an adequate PMCT recording format, which includes an identification reporting section and to make clear suggestions regarding who should be reporting the data.

In the event of a DVI, although it is possible to transfer large quantities of PMCT data between different countries [21], this process currently takes approximately 20 min per case (or longer, if there are security measures, such as firewalls in place), requires a large computer memory and storage facility, and post-processing of the data can be labour intensive (depending on the case). Therefore, a 'minimum

Table 2 The advantages and limitations of PMCT

Advantages

CT is also available as a mobile technology
 CT is not restricted to a single area of the body
 No need for lengthy preparations of bones/teeth
 CT data can be obtained and transferred virtually “as is”, i.e. without language interpretation/translation
 Storage requirements of CT data are far less problematic than whole body or tissue storage—from both an ethical and practical standpoint
 Less chance of information or evidence being lost
 Fast scan and analysis time
 Expert analysis can be done remotely and at any time
 CT is non-invasive, therefore virtual forensic procedures are likely to be culturally more acceptable
 An online, remotely accessible PMCT database could be created—providing researchers with an opportunity to improve traditional anthropological, odontological and forensic techniques

Limitations

Access to CT scanners may be limited, particularly those that are used for PMCT scanning as well as clinical scanning
 Equipment is expensive
 Continuous excessive use of scanners can cause damage which is expensive to repair
 Metal might cause artefacts (particularly evident in the dentition)
 Not all pathologies that could potentially be used for identification by comparison with antemortem medical records can be detected

dataset’ recording form, completed by a central investigator, which can be sent to numerous practitioners for independent analysis, could be of considerable benefit in DVI scenarios where time is of essence and victims must be identified accurately. A standard PMCT reporting form would also ensure that an adequate amount of information about each case was recorded in a standard format; for multiple practitioners, using numerous anthropological identification techniques to use remotely.

Future of forensic imaging and DVI

As PMCT is being increasingly accepted into autopsy practice, it is anticipated that it will, as Rutty suggested nearly 10 years ago, become a significant, if not the main radiological examination modality for MFIs. The advantages and limitations of PMCT are summarized in Table 2. As radiologists and pathologists alike become more exposed and inclined to use PMCT in autopsy practice, so others such as the police and judiciary will come to learn of its potential significant role in MFI DVI processes. There will always remain the need for an external examination of the body, along with a dental examination, but as we move into a new era of DNA technology, with the potential offered by next-generation sequencing (NGS), PMCT and NGS may become the principal technologies used in MFI investigations, as suggested by Rutty and Sajantila at the Interpol DVI Steering Group meeting, Lyon, 2014.

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

Ethical standards For this type of study, formal consent is not required. This article does not contain any studies with human participants or animals performed by any of the authors.

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