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Virtual autopsy: possible applications in cases of presumed medical malpractice

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INTRODUCTION

The conventional postmortem examination is still performed with a method which remained almost unchanged since past century.

Autopsy is a dependent-operator method and, if badly conducted, it can potentially destroy subtle findings or make the body unusable for a second examination.

In the past decades, several groups began to use cross-sectional imaging techniques to examine cadavers, with the aim of obtaine additional information that could augment or possibly replace conventional autopsy information.

Some of those tecniques are computed tomography (CT) and magnetic resonance (MR) imaging.

The introduction of postmortem CT to the field of forensic pathology represents a radical innovation, basically for the great potential in the depiction of bones and air-containing structures that this kind of exam can afford, even if this method shows a deficiency in the diagnosis of vascular pathologic conditions.

Postmortem investigation of the human vascular system is not a new topic.

The first x-ray–based postmortem angiography dates back to the end of the 1800s and was performed by injecting a solution of x-ray–opaque material into the coronary arteries of an isolated human heart. This technique of postmortem angiography remained basically unaltered during the next 100 years, the only variation was being the type of the contrast medium injected.

During recent years, several attempts to establish a minimally invasive approach by using specially designed contrast media with subsequent postmortem CT

angiography of the whole body showed promising results.

Some authors suggest that conventional autopsy, not accepted by some religions and often rejected by family members, could be replaced by non-invasive imaging and, if necessary, by minimally invasive tissue removal. The digitally acquired data could be sent to experts for further advice and could be re-used every time new needs arise.

Even if modern imaging techniques in the field of tanatology show several advantages, today there isn't enough scientific evidence to support a complete substitution of conventional autopsy with them.

THE CONVENTIONAL AUTOPSY

The systematic examination of the cadaver conducted, at the disposal of the Health Authority, for purely clinical purposes, takes the name of diagnostic confirmation; the judicial autopsy is ordered by the Judge, when it is considered necessary for the identification of the body or to establish the cause, the means, the age and the mode of death for the purposes of the judgment of responsibility.

The autopsy is usually requested and carried out in criminal cases, but can also be requested in civil law or for the resolution of social security questions.

The autopsy is a non-repeatable technical assessment; it is therefore essential its correct execution, to correctly guide the Public Prosecutor in the requests to be made to the Judge for preliminary investigations, until the promotion of the “probationary incident”. This request is made when the proof concerns a person, a thing or a place whose status is subject to non-avoidable modification or, when, if the expert's report was arranged in the trial, it could cause a suspension of more than 60 days. In cases in which a probationary incident is not proceeded, the autopsy report will constitute one of the preliminary investigations, arranged and carried out under the exclusive control of the Public Prosecutor, which may be differently used by the parties during the trial. If this one proceeds with a probative incident, the expert report will take on the value of proof and as such can be used by the parties at trial.

The autopsy report usually consists of three parts: in the first one are described exactly the anatomical-pathological data collected in the examination of the external

and internal parts and are exposed the noted findings in detail; in the second one the anatomo-pathological diagnosis of the alterations found is formulated; in the third, are precised and motivated the medical-legal diagnosis on the cause, the means, the modalities and the era of the death, considering the collected data, the information taken or received from the Magistrate and answering the various questions posed by him.

In any case, the expert opinion must always be based on safe objective data and never just on presumptions.

The Parliamentary Assembly of the Council of Europe has been involved in questions relating to autopsies. In 1990, it adopted a report on the harmonisation of autopsy rules, which contains very comprehensive and detailed information on the practices of autopsies in Europe.

Following this report, the Parliamentary Assembly adopted Recommendation 1159 (1991) on the harmonisation of autopsy rules. In this recommendation, the Assembly notes that "as the mobility of the population increases throughout Europe and throughout the world, the adoption of uniform guidelines on the way autopsy reports are to be established becomes imperative". This is particularly true in cases of mass disasters, whether natural or not, involving persons of different nationalities, for example air accidents, illegal executions or murders perpetrated by authoritarian regimes, accidental death abroad or murder cases where the victim and the perpetuator are of different nationalities.

The autoptic survey is performed whenever the Magistrate requests it. According to the Recommendation of the Council of the European Community n. R (99) 3 autopsies should be performed in all cases of non-natural, certain or suspected death, even if a certain period of time has elapsed between the reputed responsible event and the death. In particular, it must be conducted:

- in cases of certain or suspected homicide;
- in cases of suicide;
- in cases of sudden death (including S.I.D.S.);
- in cases of suspected human rights violation (torture, ill-treatment);
- in cases of iatrogenic death or in relation to "malpractice");
- road accidents,
- accidents at work;
- professional diseases;
- domestic accidents;
- natural or technological disasters;
- death in prison or in connection with police actions;
- unidentified bodies or skeletal remains.

The recommendation underlines that the autopsy report is of fundamental importance in medico-legal autopsies. The report is a permanent record of the findings and is legal document which may be referred to in legal proceedings many years later.

The report must therefore be:

1. complete and detailed;

2. clear, being comprehensible not only to other doctors, but also to non-medical readers;

3. written in a logical sequence, well-planned and easy to refer to in various sections, following a conventional pattern;

4. in permanently consultable form.

The diagnostic accounting in Italy is disciplined by the art. 37 of the Mortuary Police Regulations (Presidential Decree 10 September 1990, No. 285). It is performed when it comes to ascertaining the cause of death in the case of deceased persons without medical assistance, transported to an hospital or morgue or observation depot or in the case of the bodies of dead people in hospitals, university clinics or Private treatment institutes, whenever they are provided by the respective health directors, primary or medical doctors for the control of the diagnosis or for the clarification of clinical-scientific questions. The diagnosis can also be requested by the family doctor and will be the health coordinator of the ASL of belonging, when it comes to people who died at home due to an infectious disease or widespread or suspected of being, for the clarification of the diagnosis. Following the recent legislation on medical professional responsibility, Law 24/17, this assessment can also be requested by the relatives of the deceased.

The anatomo-pathologist doctor that, during the diagnostic finding, has the suspicion that death is to refer to a violent cause (intentional or culpable) must suspend the investigation and present the report, putting the body at the disposal of the judicial authority.

EXTERNAL EXAMINATION

The main purposes of the survey are essentially the following:

. ascertain the identity of the body;

. establish the era of death;

. specify the cause of death and then:

- to describe the external signs of injury and the various traumatological findings, without changing the physical state of the body;

- object to possible morbid findings at the time of death, or consolidated (outcomes of previous illnesses).

Apart from data concerning height, weight, gender, apparent age, skull shape, hair color, hair character, presence of lesions, scars, bony deformations, we will take note of the possible injuries, ancient or recent, and of the foreign materials present on the body, like traces of blood and other suspicious spots.

It will be necessary to assess if the collected data are enough or not to identify the body and to establish with certainty the cause of death and the era in which it dates. Otherwise, the Magistrate will be asked for the authorization to perform the judicial autopsy. If there are ligatures on the body such as loops around the neck it is a good idea to take note of the position of the knot, cut the lanyard with the scissors at a proper distance from the knot and store it properly. In the firearm and in the shot wounds it may be very important to make the holes on the clothing coincide with those of the body, in order to establish the direction in which the blows were inflicted. Care should be taken to report any traces of burns, to describe the haloes of

tattoo in the case of injuries from firearm shots, smoking, etc. This data will be important to establish the distance from which the projectile was fired. Attention should be given to the presence of liquids in the various orifices of the body. The foaming material that may be present at the mouth or nose should be collected with a swab or with a pipette and then examined in the laboratory, especially in cases where death from poisoning is suspected.

If death is suspected due to sexual assault, the state of the genital organs must be carefully assessed. The presence of sperm can be confirmed by vaginal or rectal swabs or by the material collected with a pipette, if there is enough. The examination of the mouth and lips can be very important. When death has been caused by a suffocation mechanism due to pressure on the face, tearing of the lips and impression lesions caused by the pressure of the teeth on the mucosa, an expression of the damaging force, may be noted. In the asphyxiated deaths, haemorrhages are frequently observed in the retroauricular, subconjunctival, etc. Carefully inspect the skin surface of the whole body without leaving the palms of the hands. Typical for example defense lesions in the case of aggression with cutting arms. The continuity of the wrist in cases of suicide, characterized by parallelism and in general by their considerable number, are still typical, expressing repeated attempts before the fatal cut of the arterial trunks.

INTERNAL EXAMINATION

The purposes of the investigation in the medico-legal field are to highlight all the anatomical-pathological findings (macro and microscopic) useful for the purposes of

personal identification, the assessment of the time of death and the cause of mortis. The dissection should always be carried out systematically and after understanding the meaning of the questions to be answered. We must avoid unnecessary mutilations and the body must be recomposed in any case in a satisfactory way so to be returned to the piety of the relatives.

Usually we proceed by first opening the cranial cavity, then the thoracic cavity, then the neck, the abdominal cavity, the pelvis and the limbs. Generally, an incision is made bilaterally from behind the ear and runs along the posterolateral face of the neck to the collarbone. A transverse incision is then made passing through the sternal handlebars, followed by a mid-thoracic abdominal incision up to the pubis (in the newborn the cut stops at the navel to protect the funicular vessels, then proceeds with two oblique cuts, one on the side, up to inguinal folds). The thoraco-abdominal flaps are reversed towards the sides, the cutaneous flap of the neck is reversed upwards. For what concerns the examination of the head, a bimastoid cut is made passing through the vertex and then each of the two flaps is reversed, one forward and the other back.

Regarding to the cranial bones, a circular bone cut is performed passing over the glabella and the occipital protuberance outside and the section is completed by using a chisel with a lever action placed at the level of the frontal and temporal-occipital incisions. It is necessary to be prepared in advance to collect samples of various body fluids such as blood, urine, gastric and intestinal contents, cerebral spinal fluid, bile, etc. as well as fragments of organs or tissues.

Before an organ is cut or cleaned in water, it is necessary to make a preliminary, careful inspection.

The blood necessary for the possible determination of alcohol or any substance with a narcotic action, whose circulation is suspected, should preferably be taken from the axillary vein or from the femoral vein rather than from the heart. In samples taken from the heart, during autopsy, the cardiac blood tends to be mixed with that coming from the hepatic bowel (inferior vena cava) and this can alter the alcoholic values.

Every organ extracted from its cavity must be studied in its topographical and physical aspects. The form, volume, diameters, weight, color, appearance of the surface, of the envelopes, of the margins, the consistency, the appearance of the cutting surface, etc. must therefore be specified. The technique of judicial autopsy does not differ from that of any anatomo-pathological examination. The diversity of the investigation depends from the questions that are posed to the sector expert. As we said, the latter must specify at what time death dates and above all must determine if it is murder, suicide or accident, if in the cause of the deadly event is recognizable the responsibility of third parties, such as the means used; if the lesions found on the corpse were produced in life or post-mortem; what is the duration of the eventual survival period compared to the time when the fatal injuries were produced; what is the identity of the body.

THE VIRTUAL AUTOPSY

The main finalities of forensic medicine are to document, analyze and clarify the medical-scientific evidences in living and deceased people, presenting them comprehensively in the courtrooms. In the deceased people, the goals of the autopsy examination are: to determine the cause, time, and modality of death, to assess the presence of vital signs on the damaged anatomical structures and to envisage a forensic reconstruction based on the different findings. Although the role of the autopsies in providing forensic information useful for guiding the judicial investigations is known, the basic methodology, as told above, has not undergone significant changes during the last decade. The progress and evolution of radiological sciences towards an increasingly improved definition of technical parameters enabling study of the details of the human body and its components, both in an anatomical-structural and a physiological–pathophysiological sense, has approached forensic medicine and radiology, two disciplines that only appear to be so different. Both of them are based on the study and interpretation of anatomical findings and are conducted also for research purposes, the forensic medicine is meant to clarify legal issues, while the radiology is aimed to provide rapid responses with diagnostic-operational implications. The methodological and operational approach between the two disciplines is recent, dating back to the early uses of conventional radiology in the study and detection of foreign bodies retained in the corpse.

In the 1970s, the American College of Pathologists reported on the importance of the radiographical investigation in some cases of gunshot deaths and, at the time of its introduction, it conducted studies on the use of ultrasound-guided techniques of anatomical sampling[1]. In 1984, Di Maio in Italy published a paper instructing on the correct use of radiography in the study of gunshot deaths, which immediately assumed the value of a protocol for the discipline. The prior identification of intact or fragmented bullets and their subsequent removal and reporting was considered essential for an accurate necroscopic study[2]. Over the past 20 years, radiologic examinations have become increasingly available and accessible in both practical and economic terms, leading to a closer collaboration between the two disciplines, with a move from the performing radiographic examination only in special cases to the almost routine of the postmortem radiologic investigation, universally named "virtopsy"[3,4].

The first forensic application of CT was a description of the pattern of gunshot injury to the head by Wullenweber et al in 1977[5]. Because of the limited image quality and resolution and poor postprocessing results in the early years, only a few studies correlated pathologic findings at full- body postmortem CT with forensic autopsy

1. Randall BB, Fierro MF, Froede RC (1998) Practice guideline for forensic pathology. Members of the Forensic Pathology Committee, College of American Pathologists. Arch Pathol Lab Med 122:1056–1064
2. Di Maio VJ (1984) Basic principles in the investigation of homicides. Pathol Annu 19 Pt 2:149–164
3. Thali MJ, Jackowski C, Oesterhelweg L et al (2007) Virtopsy - the Swiss virtual autopsy approach. Leg Med 9:100–104
4. Thali MJ, Yen K, Schweitzer W et al (2003) Into the decomposed body- forensic digital autopsy using multislice-computed tomography. Forensic Sci Int 134:109–114 .
5. Wullenweber R, Schneider V, Grumme T. A computer-tomographical examination of cranial bullet wounds [in German]. Z Rechtsmed 1977;80:227– 246.

findings[6,7], so the interest of forensic scientists in this new modality was not very high.

The Institutes of Forensic Medicine, Diagnostic Radiology and Neuroradiology at the University of Bern, Switzerland, they started a research project in 2000 called virtopsy.

The term "virtopsy" was created from the terms "virtual" and "autopsy." The former term is derived from the Latin word *virtus*, which means "useful, efficient, and good." The term "autopsy" is a combination of the classical Greek terms *autos* ("self") and *opsomei* ("I will see"). Thus, autopsy means "to see with one's own eyes." Because the goal was to eliminate the subjectivity implied by *autos*, the term "autos" was deleted, while the terms "virtual" and "autopsy" was merged to create the term "virtopsy"[8].

Virtopsy basically consists of body volume documentation and analysis using CT, MR imaging, and microradiology and 3D body surface documentation using forensic photogrammetry and 3D optical scanning.

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[6] Donchin Y, Rivkind AI, Bar-Ziv J, Hiss J, Almog J, Drescher M. Utility of postmortem computed to- mography in trauma victims. J Trauma 1994;37: 552–555.
[7] Schumacher M, Oehmichen M, Konig HG, Ein- ighammer H. Intravital and postmortal CT examinations in cerebral gunshot injuries [in German]. Rofo 1983;139:58 – 62.
[8] Virtopsy home page. Available at: http://www .virtopsy.com

The study was approved by the local department of justice and the Ethics Committee of the University of Bern and included 120 forensic cases involving people whose age at death ranged from 22 weeks gestation to 94 years.

Each body was wrapped in two artifact-free body bags to avoid contaminating the radiology equipment and to protect the identity of the deceased person during clinical scanning.

Since 2005 the Forensic Institute at the University of Berne has its own multi-layer Siemens TC scanner (Emotion 6, Siemens Medical Systems, Erlangen, Germany - High-speed type 6 thin slices at each rotation) only contaminated or rotted corpses are wound. For the CT scan, full-body scans were performed with a 64-layer MD CT scanner. Up to 1200 axial images were obtained with a cutting thickness of 1.25 mm and an increase of 0.7 mm. In cases of particular relevance (complex fractures, teeth, foreign bodies), scans were performed with lower thicknesses (sections of 0.5 mm and 0.625 mm of thickness), preserving the raw data for further subsequent reconstructions. The acquisition time was about 10 minutes. In the case of MRI, scans of the entire body volume and limbs were performed, when necessary, on a 1.5-T system (Signa v5.8; GE Medical Systems, Milwaukee, Wisconsin), acquiring coronal, sagittal and axial images with different weighing (T1 spin-echo, and fast spin-echo T2 sequences with and without fat saturation, inversion recovery sequences, gradient-echo sequences). When the heart had to be observed, acquisitions were made on the transaxial plane, along the short axis and the long axis. Acquisition time ranged from 1.5 to 3.5 hours.

Data analysis and postprocessing of CT and MR imaging data were performed on a Leonardo (Siemens) workstation.

In special situations, bone-tissue specimens were examined on a micro-CT system developed and built at the Institute of Medical Physics in Erlangen, Germany. This scanner can image a 3D volume with an isotropic resolution ranging from 10 to 100 mm. The system allows the examination of samples with diameters ranging from 4 to 40 mm.

Actually, the standard for the documentation of injuries in forensic medicine is still photography with exact measurements. However, like conventional radiography, the photographic process displays a 3D wound in only two dimensions.

With the TRITOP/ATOS II system (GOM, Braunschweig, Germany), the 3D color-encoded surface can be documented by means of detection of the distortion of light stripes projected onto the surface. In this way, the system can recalculate the 3D surface that caused the distortion. This system is usually used when high precision is required, because it is accurate to less than 20 mm.

This accuracy allows more detailed surface documentation compared with 3D reconstructed images from high-resolution CT data.

The color information is acquired using TRI-TOP software, which combines digital photographs of the surface taken from many different angles to create a single 3D color image of the object that can be matched up with the digital 3D surface image of the object with use of coded and uncoded markers placed on the object. With this

technology, is possible to obtaion documentation ranging from that of fine details (eg, skin lesion) to overview documentation (whole body or entire vehicle).

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. The procedure of these methods of surface scanning can be standardised through automation by the use of a robot. By comparing with further investigation data, a reconstruction of the event can be shown.

Both MSCT and MRI can be used for postmortem imaging.

The acquisition of data obtained by the PMCT before performing the conventional autopsy provides important information on less accessible body areas for conventional examination techniques (for example, the facial part of the skull, cervical spine, extremity, pelvic region) as well as the presence of foreign bodies, including projectiles deemed important to be recovered during the autopsy examination. This investigation has an important role, especially in cases of corpses in particular conditions (charred, rotting, chopped corpses, etc.).

Today, there are only a few institutions worldwide that have recognized the feasibility and possible impact of cross-sectional imaging in postmortem investigation and that have invested efforts in its implementation. For example, the Office of the Armed Forces Medical Examiner (Washington, DC; Dover, Del), the Institute of Forensic Medicine (Copenhagen, Denmark), and the Victorian Institute of Pathology (Sydney, Australia) have already installed their own CT scanners, and in

Japan, the Society for Autopsy Imaging was founded in 2003[9].

The applications of the TCMS and of the RM in this context are multiple, including:

- Identification: prior to any postmortem investigation, the identity of the body must be clarified and proved; in facts, one of the most important goals of the postmortem investigation is the reestablishment of the identity of the unidentified body. Multidetector row CT could be very useful for that. Secure post- mortem identification is possible only with DNA profiles, dental status or fingerprinting. With cranial CT data obtained in a corpse, it is possible to reconstruct any antemortem radiographic projection for comparison[10].

  In addition to morphologic findings such as an endoprosthesis of the shoulder, hip, or knee (that are often already expected with an efficient external inspection), whole-body CT reveals several findings that can be used for a positive identification[11,12] . These applications of CT technology in the forensic domain suggested that mobile machines could be used for postmortem data acquisition in cases of casualties such as an airplane crash or natural disasters.

  The main problem with wich to deal, in these cases, is the identification of the bodies, and the CT can be of inestimable value in the identification of the victims.

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[9] Dirnhofer R, Jackowski C, Vock P, Potter K, et al. Radiographics. 2006 Sep-Oct;26(5):1305-33. VIRTOPSY: minimally invasive, imaging-guided virtual autopsy.

[10] World Health Organisation (2002) Reducing risks, promoting health life. The world health report. WHO, Geneva.

[11] Mackie IJ (1999) Patterns of drowning in Australia, 1992–1997. Med J Aust 171:587–590

[12] Cummings P, Quan L (1999) Trends in unintentional drowning: the role of alcohol and medical care. JAMA 281:2198–2202

These diagnostic techniques allow to get useful data for identification of cadavers, like the age, the gender, the organ weight estimation, the body length, the individual features (dental, intracorporeal), also in conditions not reachable by routine autopsy, like in the case of cadavers carbonized or in advanced decomposition.

- Search for vital signs on damaged anatomical structures: vital reactions are important to clarify the sequence of injurious events and the cause of death in forensic pathological investigations. Determining if an injury is pre, peri or post-mortal is of fundamental judicial and medico-legal importance. Radiological investigation methods may therefore be useful in identifying, for example, indicative signs of blood circulation and respiration still present (for example, fatal hemorrhage, adipose and gaseous embolism, aspiration, subcutaneous emphysema).

  After soft-tissue emphysema is palpated, it is hardly visible at autopsy because the air disappears when the overlying skin is incised. Active swallowing of foreign material can also demonstrate that the victim was still alive when the incident happened[13].

  In case of strangulation, the bleeding into the insertions of the sternocleidomastoid muscle or soft-tissue structures of the neck proves that circulation was ongoing at the strangulation onset, and the strong breathing attempts against the occluded airways causes alveolar ruptures with subsequent

[13] Pomara C, Fineschi V, Scalzo G, Guglielmi G (2009) Virtopsy versus digital autopsy: virtuous autopsy. Radiol med. 114:1367–1382

pneumomediastinum[14] and soft-tissue emphysema ascending into the neck.

- Search for foreign bodies (bullets, metal fragments, inserted foreign bodies).
- Time, cause and mode of death: one of the bigger problems of forensic medicine is the evaluation of time elapsed from the time of death. MR spectroscopy is able to provide an estimate of this time starting from metabolic information obtained from the analysis of predefined encephalic regions.

  The above diagnostic techniques are able to provide information on the possible causes of death, in particular in the case of polytrauma, drowning, burns, hanging, gunshot wounds.

  - Gunshot injuries: in these case knowing the bullet's location before starting physical autopsy will save the pathologist time. In this case, postmortem radiology is useful to locate the projectile entry and exit wounds, to depict the bullet course and may help in identifying the ammunition and the weapon type utilised[15].

    It would be appropriate to perform the PMCT examination between conventional external examination and conventional autopsy.

    Regarding "native" PMCT (examination without administration of contrast medium), areas with injuries can be found by the presence of air bubbles, bleeding sources and small foreign bodies (e.g. fragments of the bullet). Distinguishing entry holes is possible based on: shape of lesions, comparison of external wounds on different sides of the body, position

[14] O'Mara MS, Battistella F (2004) Do we still need autopsies. Curr Surg 61:151–155

of fragments of fractured bones.

By the bevelling of bone fractures, we are able to indicate the direction of a gunshot. With the application of PMCT—angiography (PMCTA)[15,16], 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, and will be a valuable piece of evidence. In many cases, it is easy to individuate the whole injury track of the chest. Problems are, however, the injuries in the abdomen.

In some cases, the gunshot's direction doesn't reflect the closest path between the entrance wound and the location of the bullet/exit wound, because the bullet can be deflected due to contact with bones. In other cases, the bullet is lodged at a distant location to what was expected. With the application of the PMCTA, we have the opportunity to visualise the actual injury track and the vascular and internal organs injuries.

- Sharp trauma cases: in general, sharp trauma cases can be even more complicated than ballistic trauma cases. In a number of cases, external injuries can be visible in native PMCT due to air bubbles or blood; using

[15] Grabherr S, Doenz F, Steger B, Dirnhofer R, Dominguez A, Sol- lberger B, Gygax E, Rizzo E, Chevallier C, Meuli R, Mangin P (2011) Multi-phase post-mortem CT angiography: development of a standardized protocol. Int J Legal Med 125(6):791–802

[16] Ross SG, Bolliger SA, Ampanozi G, Oesterhelweg L, Thali MJ, Flach PM (2014) Postmortem CT angiography: capabilities and limitations in traumatic and natural causes of death. Radiographics 34(3):830–846

PMCTA can add the focal leak-age of the contrast medium. In some cases, the weapon of crime or a small piece of it can be left inside the body [17] (e.g. the blade of the knife),[18,19] allowing the match between the recovered foreign body and 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. The investigation possibilities can be considerably expanded with the results of PMCTA, from which we can obtain the injury canal of internal organs and the location of injuries of vessels[20] . Unfortunately, in cases with multiple stab injuries, they can overlap their injury tracks. In cases with pulmonary injuries Germerott et al.[21] used post-mortem ventilation (VPMCT) for a better visualisation.

- Brain trauma: the increase intracranial pressure as a result of trauma or ischemia typically manifests in the autopsy like a transtentorial herniation of the temporal lobe or herniation of the cerebellum into the

[17]Winskog C (2012) Precise wound track measurement requires CAT scan with object in situ: how accurate is post-mortem dis- section and evaluation? Forensic Sci Med Pathol 8(1):76–77

[18]Ebner L, Flach PM, Schumann K, Gascho D, Ruder T, Christe A, Thali M, Ampanozi G (2014) The tip of the tip of the knife: stab sequence reconstruction using postmortem CT in a homi- cide case. J Forensic Radiol Imaging 2(4):205–209

[19] Kawasumi Y, Hosokai Y, Usui A, Saito H, Ishibashi T, Funayama M (2012) Postmortem computed tomography images of a broken piece of a weapon in the skull. Jpn J Radiol 30(2):167–170

[20] Palmiere C, Binaghi S, Doenz F, Bize P, Chevallier C, Mangin P, Grabherr S (2012) Detection of hemorrhage source: the diag- nostic value of post-mortem CT-angiography. Forensic Sci Int 222(1–3):33–39

[21] Germerott T, Preiss US, Ross SG, Thali MJ, Flach PM (2013) Postmortem ventilation in cases of penetrating gunshot and stab wounds to the chest. Leg Med (Tokyo) 15(6):298–302

foramen magnum[22].

The use of PMCT is particularly useful when an autoptic assessment of brain structures is just impossible to do because of the advanced putrefaction, or when there are exposed cranial fractures with loss of brain tissue. In such cases, mostly postmortem MR imaging provides an adequate anatomic overview of the brain in situ and allows exclusion of pathologic alterations[19].

- Cardiac deaths: the majority of natural deaths are caused by cardiac insufficiency. Chronic cardiac diseases (eg. cardiomyopathies) or acute ischemic situations can induce cardiac insufficiency.

  Injuries to the heart typically manifest at postmortem imaging as pericardial tamponade and hematothoraces.

  Even the right ventricular failure after venous air embolism in cranial trauma (eg, gunshot wounds to the head, stab wounds to the neck) is a very common heart-related cause of death. In contrast to traditional autopsy techniques, post-mortem CT allows detailed 3D visualization of the embolized structures, with quantification of the embolized air[23,24].

- Pulmonary pathologies and lesions: pneumothoraces are easily detected

[22] Winklhofer S, Stolzmann P, Meier A, Schweitzer W, Morsbach F, Flach P, Kneubuehl BP, Alkadhi H, Thali M, Ruder T (2014) Added value of dual-energy computed tomography versus single-energy computed tomography in assessing ferromagnetic properties of ballistic projectiles: implications for magnetic reso- nance imaging of gunshot victims. Invest Radiol 49(6):431–437

[23] Jackowski C, Thali M, Sonnenschein M, et al. Vi- sualization and quantification of air embolism structure by processing postmortem MSCT data. J Forensic Sci 2004;49:1339 –1342.

[24] Jackowski C, Sonnenschein M, Thali M, et al. In- trahepatic gas at postmortem CT: forensic experi- ence as a potential guide for in vivo trauma imag- ing. *J Trauma.* 2007;62:979–98 .

at postmortem imaging[25]. Pulmonary edema, which is often seen in cardiac deaths, has postmortem imaging characteristics comparable to clinical imaging results, such as increased ground-glass attenuation at CT or increased signal intensity at MR imaging. Pneumonia also causes pulmonary hyperattenuation and hyperintensity[26]. Pulmonary alterations can be masked by blood sedimentation (internal livores), which should not be interpreted as local pneumonia.

In typical drowning cases, the lungs manifest an "emphysema aquosum" along the retrosternal face of the upper lobes[9]. The presence of drowing liquid within the gastro-intestinal tract is indiciative of vitality at the time of the drowing.[27]

In addition, the post-mortem imaging techniques have proven useful in correlating the death as an outcome of different ways: accident, suicide, homicide, natural causes or iatrogenic.

- Reconstruction of the physiognomy traits: another application of modern imaging techniques in this field concerns the possibility of reconstruction of probable physiognomic traits of a person through the cranial morphology taken by radiographic or CT, on the basis of the

[25] Thali MJ, Yen K, Schweitzer W, et al. (2003) Virtopsy, a new imaging horizon in forensic pathology: virtual autopsy by postmortem multislice computed to- mography (MSCT) and magnetic resonance imag- ing (MRI)—a feasibility study. J Forensic Sci;48:386 – 403.

[26] Jackowski C, Dirnhofer S, Thali M, Aghayev E, Dirnhofer R, Sonnenschein M. Postmortem diag- nostics using MSCT and MRI of a lethal strepto- coccus group A infection at infancy: a case report. Forensic Sci Int 2005;151:157–163.

[27] Aghayev E, Thali MJ, Sonnenschein M, et al. Fatal steamer accident: blunt force injuries and drowning in post-mortem MSCT and MRI. Fo- rensic Sci Int 2005;152:65–71.

widely shared theory that there is a significant interconnection between the individual morphology of the skull (genetically determined and regulated) and of the face.

- Paleoradiology: another discipline in which postmortem cross-sectional imaging is of inestimable value is paleoradiology. The human or animal remains of past cultures can be investigated without disturbing them, providing information regarding the age and gender, or their injuries or diseases[28,29].

Advantages and limits

Several studies have shown that virtual autopsy holds great potential to aid forensic investigations[30,31,32,33].

The documentation and analysis of postmortem findings with MSCT and MRI and postprocessing techniques seem to be investigator-independent, objective and non-invasive, and so they will lead a certain improvement in forensic pathologic

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[28] Magid D, Bryan BM, Drebin RA, Ney D, Fishman EK. Three-dimensional imaging of an Egyptian mummy. Clin Imaging 1989;13:239 –240.

[29] zur Nedden D, Knapp R, Wicke K, et al. Skull of a 5,300-year-old mummy: reproduction and inves- tigation with CT-guided stereolithography. Radi- ology 1994;193:269 –272.

[30] Thali MJ, Schweitzer W, Yen K et al (2003) New horizons in forensic radiology: the 60-second digital autopsy-full-body examination of a gunshot victim by multislice computed tomography. Am J Forensic Med Pathol 24:22–27

[31] Thali MJ, Yen K, Schweitzer W et al (2003) Virtopsy, a new imaging horizon in forensic pathology: virtual autopsy by postmortem multislice computed tomography (MSCT) and magnetic resonance imaging (MRI) – a feasibility study. J Forensic Sci 48:386–403

[32] Ros PR, Li KC, Vo P et al (1990) Preautopsy magnetic resonance imaging: initial experience. Magn Reson Imaging 8:303–308

[33] Thali MJ, Taubenreuther U, Karolczak M et al (2003) Forensic microradiology: micro-computed tomography (Micro-CT) and analysis of patterned injuries inside of bone. J Forensic Sci 48:1336–1342

investigation.

Image acquisition and postprocessing with MSCT require less time than a complete autopsy. The virtual examination may also decrease the time required for the autopsy, because the pathologist could be armed with prior knowledge.

Autopsy specimens such as tissue sections are difficult to store indefinitely. Digitally acquired data could instead be consulted whenever new forensic issues arise, or they could be sent to other experts for a second opinion.

By PMCT it is possible to evaluate the size and weight of the organs, highlight pathological conditions, neoformations and cysts (myocardial hypertrophy, goiter, hepato-splenomegaly, hepatic steatosis, hepatic and renal cysts).

A complete autopsy includes first of all an external examination for the documentation of sure signs of death (rigor mortis, livores, putrefaction, injuries not compatible with life) and other external findings. Livores and putrefaction are visible with pmCT as internal livores and intravascular gas[34]. Nevertheless, rigor mortis or punction marks cannot be assessed with pmCT. Therefore, the external examination cannot be completely replaced by imaging methods.

Information on organ colour, not only characteristic for myocardial infarction, but also other characteristic colour like icterus, antracosis or colour of ascites, pleural or pericardial effusion, bile, stomach and intestinal content and "nutmeg liver" (sign of chronic passive congestion of the liver) are not visible.

The results show that the reconstruction of the pathogenetic mechanism is still

[34] Germerott T, Preiss US, Ebert LC, Ruder TD, Ross S, Flach PM, Ampanozi G, Filograna L, Thali MJ (2010) A new approach in virtopsy: postmortem ventilation in multislice computed tomography. Leg Med (Tokyo) 12:276–279

difficult. Thus, an interdisciplinary discussion of PMCT results with autopsy results and the clinical progression of each case would be desirable for the most valid cause of death diagnosis. There are special areas in which PMCT may also turn out to be superior to classic autopsy: the results show that PMCT is an excellent tool for the assessment and documentation of calcified lesions and bones. Histological evaluation of calficated lesions takes a long time. Furthermore, the comparison between post-mortem imaging and the results of ante-mortem clinical tests, such as coronary angiography, is very simple and easily accessible for physicians. The extremities are examined only on very rare occasions, in order to not mutilate the body. Musculoskeletal system disorders, particularly of the viscerocranium and extremities, are therefore easily misunderstood in conventional autopsies.

In cases of metallic implants, beam hardening artefacts occur on pmCT images, impairing assessment of underlying structures.

Vessels and organs are opened for macroscopic examination at autopsy. Therefore, air accumulations, such as sub-cutaneous emphysema, intravascular or intrapericardiac air and aerobilia, are more efficiently visualized and documented with pmCT than at macroscopic examination.

The same applies to small pleural effusions and small pneumothoraces.

With the opening of the body cavities, there is a pressure release; In this way, intracavitary lesions, such as hiatal or inguinal hernias, become invisible to macroscopic examination, but are easily recognizable with PMCT. The presence of catheters and tracheal tubes can be documented three-dimensionally with PMCT.

Compared to CT images from living patients, with pmCT, we do not have to deal with motion artefacts or limitation of dose of radiation[35].

The signs of vitality of the lesions need to be confirmed by macroscopic and histological analysis, in order to exclude an artificial extravasation, or blood coagulation post-mortem

There are also some diagnostic limitations, for example, a limited soft tissue contrast or the visualization of the vascular system. In recent years, contrast medium has been introduced in postmortem cases, with the development of several techniques of PMCT angiography (PMCTA) and standardized protocols to make them easily reproducible.

[35] Westphal SE, Apitzsch J, Penzkofer T, Mahnken AH, Knüchel R (2012) Virtual CT autopsy in clinical pathology: feasibility in clinical autopsies. Virchows Arch. 461:211–219

THE PMCT ANGIOGRAPHY (PMCTA)

In 1899 was born the technique of post-mortem angiography (PMA). In fact, in this year, for the first time ever, radio-opaque materials were used in isolated human hearts' coronaries.[36] In the last two decades, post-mortem radiology research has grown considerably. In the past most of the PMA methods could be used only to isolated organs and, therefore, were not suitable for use in modern postmortem imaging techniques. There was great difficulty in introducing this radiological survey into autopsies because the techniques usually used in clinical angiography are not simply transferable to post-mortem applications.

To perform PMA, the simple injection of contrast agent in a vessel, like it happens in clinical radiology, is not enough[37]. Because of the end of the intravascular circulation, haemostasis, agonic process and post-mortem changes, most of the vascular system is empty and sometimes blood clots or gas could be found[38]. It is therefore necessary to introduce a high volume of perfusion liquid[16], of a specific type, since the water-soluble contrast agents rapidly diffuse out of the corpse lumen of the cadaver.

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[36] Schoenmackers J (1960) Technik der postmortalen angiogra- phie MIT berücksichtigung verwandter methoden postmortaler Gefäßdarstellung. Ergeb Allg Pathol Anat 39:53–151

[37] Grabherr S, Grimm J, Baumann P, Mangin P. Radiol med. 2015 Sep;120(9):824-34. Application of contrast media in post-mortem imaging (CT and MRI)

[38] Egger C, Bize P, Vaucher P, Mosimann P, Schneider B, Dominguez A, Meuli R, Mangin P, Grabherr S (2012) Distribu- tion of artefactual gas on post-mortem multidetector computed tomography (MDCT). Int J Leg Med 126:3–12

The behavior of injected liquids depends by the kind of liquid (oily, corpuscular mixture, aqueous, etc.) and its physical properties (viscosity, osmolarity, radio-opacity, etc.). It's necessary to use a specific contrast agent that produces good vascular contrast without too many artefacts[37].

The analysis of the most accredited scientific literature on the subject shows that over the years two different approaches were used, one that used aqueous liquids, the other the oil liquids. After death, the permeability of the vascular wall increases significantly and, therefore, the injection of a water-soluble liquid leads to a rapid extravasation of the same from the vascular lumen in the surrounding tissue[39]. Therefore the application of water-soluble liquids is limited to a short period after death or to specific techniques, such as targeted angiography of the coronary arteries[40,41].

To limit extravascular diffusion of aqueous liquids, some Auhtors[42] proposed adding hydroscopic polyethylene glycol (PEG) as a contrast agent dissolver. PEG consists of large polymerised molecules that remain in the vessel lumen, even if some studies have shown some limitations, as the hydroscopic abilities of the mixture tend to

[39] Grabherr S, Djonov V, Friess A, Thali MJ, Ranner G, Vock P, Dirnhofer R (2006) Postmortem angiography after vascular perfusion with diesel oil and a lipophilic contrast agent. AJR 187:W515–W523

[40] Roberts IS, Benamore RE, Peebles C, Roobottom C, Traill ZC (2011) Diagnosis of coronary artery disease using minimally invasive autopsy: evaluation of a novel method of post-mortem coronary CT angiography. Clin Radiol 66:645–650

[41] Lizuka K, Sakamoto N, Kawasaki H, Miyoshi T, Komatsuzaki A, Kikuchi S (2009) Usefulness of contrast-enhanced postmor- tem CT. Innervision 24:89–92

[42] Jackowski C, Bolliger S, Aghayev E, Christe A, Kilchoer T, Aebi B, Périnat T, Dirnhofer R, Thali MJ (2006) Reduction of post- mortem angiography-induced tissue edema by using polyethylene glycol as a contrast agent dissolver. J Forensic Sci 5:1134–1137

attract water from the surrounding tissue, leading to clumping of the remaining blood in the vessels, which could mask a thrombosis. Also, the contrast agent mixing with blood can be a problem, for example, it will no longer possible to quantify the volume of a vital haemorrhage after PMCTA.

Oily liquids mostly remain intravascular[43,44].

One of the most important parameters for the injection of oily liquids is the viscosity, in fact visualisation of the mircrovascular system is possible using low-viscosity oil as it happens in micro-angiography[45], but if the viscosity is too low, artefactual extravasation is observed, especially in regions of so-called locus minoris resistentiae[40], meaning regions with early bacterial decomposition and autolytic activities, such as the gastro-intestinal tract.

Regardless of the contrast media used, they can potentially alter the composition of fluid-based biological samples and interfere with specific post-mortem investigations. A few studies have investigated the influence of different contrast media. These studies pertain to MPMCTA and TCA and their influence on toxicology[46,47], bio-

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[43] Grabherr S, Gygax E, Sollberger B, Ross S, Oesterhelweg L, Bolliger S, Christe A, Djonov V, Thali MJ, Dirnhofer R (2008) Two-step post-mortem angiography with a modified heart-lung machine: preliminary results. AJR 190:345–351

[44] Barmeyer J (1968) Postmortale koronarangiographie und per- fusion normaler und pathologisch veränderter herzen, messung der durchflusskapazität interkoronarer anastomosen. Beitr Pathol Anat 137:373–390.

[45] Grabherr S, Hess A, Karolczak M, Thali MJ, Friess S, Kalender W, Irnhofer R, Djonov V (2008) Angiofil®-mediated visualiza- tion of the vascular system by microcomputed tomography: a feasibility study. MRT 71:551–556.

[46] Rutty GN, Smith P, Barber J, Amorosa J, Morgan B (2013) The effect on toxicology, biochemistry and immunology investiga- tions by the use of targeted post-mortem computed tomography angiography. Forensic Sci Int 225:42–47

[47] Palmiere C, Grabherr S, Augsburger M (2014) Postmortem com- puted tomography angiography, contrast medium administra- tion and toxicological analyses in urine. Leg Med. http://dx.doi. org/10.1016/j.legalmed.2014.12.005.

chemistry[48], microbiology[49], genetics[50], histology, and fatty embolism evaluation[51,52] . Therefore, the recommendation remains that before the injection of the contrast medium should be sampled as many specimens as possible, as described by Schneider et al.[53]

Actually, the MPMCTA is the most used and explored PMCTA technique.

This method was published for the first time in 2011[16] and was developed by a research group at the University of Lausanne's Forensic Medicine Center.

A mixture of medium-viscosity paraffin oil (paraffinum liquidum) and an oily contrast agent (Angiofil®, 6 %) is injected via unilateral cannulation of the femoral vessels, or in some cases, the axillar vessels[54]. The injection is performed using a Virtangio® perfusion device. MPMCTA is characterized: an arterial phase, a venous

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[48] Grabherr S, Widmer C, Iglesias K, Sporkert F, Augsburger M, Mangin P, Palmiere C (2012) Postmortem biochemistry per- formed on vitreous humor after postmortem CT-angiography. Leg Med 14:297–303

[49] Palmiere C, Egger C, Grabherr S, Jaton-Ogay K, Greub G (2014) Postmortem angiography using femoral cannulation and postmortem microbiology. Int J Leg Med. doi:10.1007/ s00414-014-1099-5

[50] Rutty GN, Barber J, Amoroso J, Morgan B, Graham EA (2013) The effect on cadaver DNA identification by the use of targeted and whole body post-mortem computed tomography angiogra- phy. Forensic Sci Med Pathol 9:489–495

[51] Palmiere C, Lobrinus JA, Mangin P, Grabherr S (2013) Detec- tion of coronary thrombosis after multi-phase postmortem CT- angiography. Leg Med 15:12–18

[52] Capuani C, Guilbeau-Frugier C, Mokrane FZ, Delisle MB, Marcheix B, Rousseau H, Telmon N, Rougé D, Dedouit F (2014) Tissue microscopic changes and artefacts in multi-phase post-mortem computed tomography angiography in a hospital setting: a fatal case of systemic vasculitis. Forensic Sci Int 242:e12–e17. doi:10.1016/j.forsciint.2014.06.039 (epub, ahead of print)

[53] Schneider B, Chevallier C, Dominguez A, Bruguier C, Elandoy C, Mangin P, Grabherr S (2012) The Forensic radiographer: a new member in the medico-legal team. Am J Forensic Med Pathol 33:30–36

[54] Pomara C, Bello S, Grilli G, Guglielmi G, Turillazzi E (2014). Multi-phase postmortem CT angiography (MPMCTA): a new axillary approach suitable in fatal thromboembolism. Radiol Med (epub ahead of print)

phase and the final dynamic phase during which PMCT data is acquired simultaneously with perfusion of the body.

The interpretation of the obtained images needs training and experience, because some post-mortem changes can imitate pathological findings[55,56] . However, a recent study showed that the artefacts observed after MPMCTA are reproducible in terms of their localisation and type, making them relatively easy to recognise[57] .

In Japan a special technique has been introduced, namely a PMCTA with cardiopulmonary resuscitation (CPR).

In this Contry, the rate of PMCT is high (over 20,000 cases per year)[58], instead the autopsy rate is very low, due to traditional reasons.

CPR is used to propel the contrast agent through the vascular system. Normal clinical aqueous contrast media is injected into peripheral veins, such as the cubital vein, just like happens in clinical in vivo contrast-enhanced CT investigations. The contrast agent then enters the heart cavities, from where it is dispersed into the pulmonary and body circulation by repeated chest compression. The technique is preferably performed in cases of prior unsuccessful CPR because this chest compression can

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55 Berger N, Martinez R, Winklhofer S, Flach PM, Ross S, Ampa- nozi G, Gascho D, Thali MJ, Ruder TD (2013) Pitfalls in post- mortem CT-angiography—intravascular contrast induces post- mortem pericardial effusion. Leg Med 15(6):315–317

56 Grabherr S, Wittig H, Dedouit F, Wozniak K, Vogel H, Heine- mann A, Fischer F, Moskala A, Guglielmi G, Mangin P, Grimm J (2015) Letter on Pitfalls in post-mortem CT-angiography—Intra- vascular contrast induces post-mortem pericardial effusion. Leg Med (epub ahead of print)

57 Bruguier C, Mosimann PJ, Vaucher P, Uské A, Doenz F, Jack- owski C, Mangin P, Grabherr S (2013) Multi-phase postmortem CT angiography: recognizing technique-related artefacts and pit- falls. Int J Leg Med 127:639–652

58 Okuda T, Shiotani S, Sakamoto N, Kobayashi T (2013) Back- ground and current status of postmortem imaging in Japan: short history of “Autopsy imaging (Ai)”. Forensic Sci Int 225:3–8

cause injuries, such as rib fractures. Organ injuries and localisation of the source of haemorrhage are visible due to extravasation of the contrast media.

Some other approaches of whole-body PMCTA have been reported in the literature[50, 59, 60, 61, 62]. A method reported by the Swiss Virtopsy® team uses an approach similar to MPMCTA; it consists in the cannulation of the femoral vessels of one side of the body and the injection of an aqueous contrast agent solution[61].

Some authors have also proposed to leave the injected contrast agent in the vessels for 15–20 min before performing the CT scan, allowing it to diffuse out of the vascular bed and leading to contrast enhancement. The body was also proposed to be scanned once in a prone position to reach complete filling of the right coronary artery[62], even if some artefacts were encountered in this method.

Instead of the PMCTA full body tecniques, targeted PMCTA tecniques are based on the filling of a specific part of the vascular system, most commonly the coronary arteries. This goal is achieved by inserting a catheter into the ascending aorta.

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[59] Jackowski C, Thali M, Sonnenschein M, Aghayev E, von All- men G, Yen K, Dirnhofer R, Vock P (2005) Virtopsy: postmor- tem minimally invasive angiography using cross section techniques—implementation and preliminary results. J Forensic Sci 50:1175–1186

[60] Jackowski C, Persson A, Thali MJ (2008) Whole body postmor- tem angiography with a high viscosity contrast agent solution using poly ethylene glycol as contrast agent dissolver. J Forensic Sci 53:465–468

[61] Ross S, Spendlove D, Bolliger S, Christe A, Oesterhelweg L, Grabherr S, Thali MJ, Gygax E (2008) Postmortem whole-body CT angiography: evaluation of two contrast media solutions. AJR 190:1380–1389

[62] Jolibert M, Cohen F, Bartoli C, Boval C, Vidal V, Gaubert JY, Moulin G, Petit P, Bartoli JM, Leonetti G, Gorincour G (2011) Postmortem CT-angiography: feasibility of US-guided vascular access. J Radiol 92:446–449

Two kinds of targeted PMCTA tecniques was been developed in England. Both of them use the left carotid artery for access but they have some differences; the method developed in Leicester consists of the injection of air [63] and uses a power-contrast injector[64], while the one developed in Oxford uses only positive contrast media[40] and uses manual injection into the carotid artery. Because the methods use aqueous contrast agents, there is a rapid extravasation out of the vascular lumen and the scanning has to be done during or immediately after injection. However, due to the small quantity of contrast agent applied for targeted PMCTA, no important tissue oedema is observed.[64]

In contrast antemortem angiography, postmortem CT angiography does not involve imaging artifacts because of the lack of subject motion.

It is also important to distinguish between artefacts related to coaugulative events and ante-mortem tromboembolic events.

In cases with a fast dying process, there are little chances of having clots in the angiography tc post mortem. In contrast, cases with a protracted dying process (eg. chronic cardiac failure, cancer, or sepsis) exhibit extensive post-mortem clotting. The formation of postmortem clotting appears predominantly in the right side of the heart, the pulmonary trunk, and the great vessels. At this time, the timelines suitable for carrying out a post-mortem CT angiography have not been identified.

[63] Rutty G, Raj V, Saunders S, Morgan B (2011) Air as a contrast medium for targeted post-mortem computed tomography cardiac angiography. Acad Forensic Pathol 1:144–145

[64] Robinson B, Barber J, Morgan B, Rutty GN (2012) Pump injec- tor system applied to targeted post-mortem coronary artery angi- ography. Int J Leg Med 127:661–666.

The speed of decomposition depends largely on external factors, which are different for each case. The increasing volume of intravascular and intraparenchymal gas accumulating during decomposition impairs image quality, predominantly in the parenchymal organs. On the studies experience, postmortem CT angiography may even provide sufficient information about the vascular status or traumatic lacerations of larger vessels also in cases with advanced decomposition.

A study conducted by Palmiere[21] et al. showed that MPMCTA is even more sensitive than ante-mortem CT-angiography. The improved sensitivity may be due to the use of a standardized MPMCTA technique consisting of at least three angiographic phases, whereas clinical radiological investigations are mostly carried out in emergency situations with only one contrast-enhanced phase. Moreover, the total dose of contrast material injected is far higher in MPMCTA than in clinical CTA. Lastly, post-mortem CT-scans and PMCTA are performed using high radiation doses and very thin slice thicknesses in order to obtain high resolution and excellent image quality, which cannot always be performed in clinical practice.

Ross et al.[16] studied the possible applications of the postmortem CT Angiography in different body regions.

Regarding the study of encephalic circulation, the enhancement of the cerebral cortex after arterial injection of a contrast medium allows better distinction of gray and white matter and so allows to see the entire cerebral vasculature of the deceased. Focal parenchymal pathologic conditions may be better detectable after contrast

medium administration. In cases of intracranial hemorrhage, the exact location of bleeding sources can be tracked because of the extravasation of contrast medium in these areas. Postmortem CT angiography facilitates the specification of the intracranial bleeding in case of epidural, subdural, subarachnoid, or parenchymal hematoma. Postmortem images appear similar to clinical angiographic images, but the postmortem perfusion status of the brain doesn't match the exacts conditions in vivo. For example, vascular spasms caused by subarachnoid hemorrhage usually disappear after death and appear like normal brain perfusions.

The craniocervical region is particularly challenging to be dissected for the coroner. Furthermore, respecting the integrity of the cadaver is extremely complicated when searching for autopsy findings in anatomic districts like the inferior skull base and the intraosseous course of the internal carotid or vertebral artery, which are in fact rarely described in medico-legal relports.

Pathologic conditions like ruptures or dissections of the vertebral arteries or the internal carotid could be related to the cause of death and they're hard to discover and usually not investigated in classic autopsy. Postmortem CT angiography has a deep advantage in analize these pathologic conditions with precision and minimal invasiveness. In addition, in cases with traumatic brain or cervical spine injury, the contrast medium often leaks into the spinal canal.

Regarding the evaluation of cardiac circulation, contrast media filling during post-mortem CT angiography allows luminal distention and shows coronary pathologic

conditions. Postmortem CT angiography allows adequate display of the coronary arteries in situ. Potentially fatal abnormalities like stenosis of a coronary artery are well shown. Anyway, the complete diagnosis of myocardial ischemia relies on histopathologic changes to the myocardium and should be evaluated with postmortem image-guided biopsy[65].

In addition, congenital anomalies such as myocardial bridging or the anomalous origin of coronary arteries are also well depicted with postmortem CT angiography [66]. The preparation and examination of cardio-vascular bypasses require a lot of time during the traditional autopsy process because of the presence of scar tissue around the bypasses (which have a small diameter) and the vascular anastomoses that need to be dissected. Postmortem CT angiography facilitates the localization of the bypasses before classic autopsy, helps the coroner avoid the destruction of any relevant findings during autopsy and allows in situ three-dimensional evaluation of cardiovascular bypasses. The filling of the heart chambers with contrast medium allows a better assessment of myocardial pathologic conditions like myocardial scarring or myocardium traumatic lacerations. Myocardial tearing causes a distinct extravasation of contrast medium into the adjacent area of pericardial tamponade that could potentially define the exact location of the injury or ischemic wall breakage.

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[65] Bolliger SA, Filograna L, Spendlove D, Thali MJ, Dirnhofer S, Ross S. Postmortem imaging-guided biopsy as an adjuvant to minimally inva- sive autopsy with CT and postmortem angiog- raphy: a feasibility study. AJR Am J Roentgenol 2010;195(5):1051–1056.

[66] Morales AR, Romanelli R, Boucek RJ. The mural left anterior descending coronary artery, strenu- ous exercise and sudden death. Circulation 1980; 62(2):230–237.

In forensic medicine, pulmonary embolism is a frequent natural cause of death and in many cases is not assessable with unenhanced postmortem CT. Clotting is often present, and no further differentiation between a finding of pulmonary embolism and a postmortem clotting can be made at postmortem CT. Antegrade perfusion of the venous system via the femoral vein allows excellent depiction of the pulmonary arteries after the filling of the right atrium and ventricle. The diagnosis of pulmonary embolism must then be confirmed by histopathologic examination of the the material taken. Postmortem CT angiography also allows the depiction of contrast medium extravasation into the trachea in cases of bronchial erosion or laceration, instead unenhanced postmortem CT would depict only nonspecific fluid within the lower airways.

Postmortem CT angiography allows the depiction of the entire thoracic and abdominal aorta, including branches like the mesenteric arteries, the celiac trunk and the renal arteries, which lead to the correct diagnosis of aneurysms, ruptures, and dissections. The quality of postmortem images at the level of the aortic root is better than the quality of clinical (ante-mortem) images because there aren’t movement artifacts.

The enhancement of the abdominal organs at postmortem CT angiography is similar to that at antemortem arterial-phase contrast medium enhanced CT, with intense arterial enhancement of the renal cortex, pancreas, spleen, and gastric and intestinal

wall. The hepatic tissue shows maximum enhancement that is due to the retrograde perfusion during the venous injection.

Regarding the body extremities, the arteries of the upper and lower extremities are well depicted at postmortem CT angiography, which allows the display of traumatic lacerations of peripheral vessels. Although injuries to the extremities do not usually lead to death, they can indirectly contribute to it. Finally, a correct depiction of the injuries inflicted on the extremities may help during the reconstruction of an accident.

MALPRACTICE AND VIRTUAL AUTOPSY

The particular interest in the thematics related to medical professional liability stems from the finding of numerous data that show that in Italy, as in many developed Countries, in the last decades there has been a worrying increase in complaints to the Judicial Authority related to alleged medical malpractice.

In this regard it is to be considered that, according to ANIA data (National Association of Insurance Companies), the number of claims reported to Italian insurance companies in the civil law sector in the health sector has increased significantly in the period 1995-2014. In fact, the increase in claims reported is characterized by the transition from 17,303 cases in 1995 to 28,504 in 2014. There has been a decrease in the number of such complaints both in 2015 (18,795 claims reported) and in 2016 (14,803 reported claims), but this decline could, at least in part, depend on a contraction in the number of policies in the insurance companies portfolio[67].

The national and international literature on the phenomenon of contentious for medical responsibility has further expanded in recent years in parallel with the increase in the contentious itself[68].

The epidemiological analysis carried out by some authors, study groups, institutions and scientific associations are an important tool for understanding the problem above all on the topic of medical error and methods and measures to reduce its frequency.

[67] ANIA. L'assicurazione Italiana. 2015/2016 – 2016/2017.
[68] Fiori A. et al. Medicina legale e della responsabilità medica. Nuovi profili. Vol. 3. 2009. Giuffrè.

It would therefore be useful to verify the usefulness of the implementation of modern diagnostic methods for images in the field of tanatology also, and above all, in cases of alleged medical professional responsibility.

About forty years have passed since Richard J. John wrote in a famous treatise on Internal Medicine that legal actions, or their threat from medical errors, were increasing and that there was no reason to believe that in the future they could to decrease.

The term "responsibility" appears for the first time in France and in England in 1787. With it the philosophers intend "the possibility to predict the effects of their behavior and to correct it based on this prediction", while for the Magistrates "the concept of responsibility presupposes that of illicit". [69]

The responsibility finds its foundation in the notion of choice, which in turn refers to the concept of freedom, not absolute, but possible and therefore motivated and conditioned by the laws in force.

The freedom of the doctor is a freedom "situated, framed in reality, under condition and relative" to the rules of art and science, to laws, to ethics and ethics.

The concept of responsibility appears, however, different from that of imputability, which means the attribution of an illecit action to a human conduct that has violated the rules of the legal system.

"It is illegal - wrote Bilancetti - what a rule considers prohibited and the legal system, depending on the degree of unlawfulness, gives you as a consequence a sanction [...]

[69] Bilancetti M., La responsabilità penale e civile del medico, Cedam Ed., Padova, 1998.

that will be punitive towards the author of the unlawful and sometimes even (in the interests of the injured) compensation and, in a general and future perspective, especially preventive "[70].

The offense can be penal, when it is considered a violation of the fundamental rules for the cohabitation of citizens; civil, when it derives from the violation of rules aimed at protecting private interests; administrative, when it is done to the detriment of the public administration.

Physicians-surgeons and dentists are also subjected to the disciplinary power of the Orders for infractions committed both towards general duties and in relationships with patients, colleagues, and public and private bodies on which they depend or to which they are bound. from a contract.

While acknowledging that, as noted by Parodi and Nizza, since the beginning of the eighties there has been a real "re-foundation" of the theories of guilt that are found in the jurisprudence of legitimacy and merit, it is certain that the doctrinal movement, which supports and sometimes precedes the jurisprudential one, it often seems to have taken steps forward only in one direction, that of the rights of the sick, who often come not abstractly without analyzing them in their real nature, and therefore in their limits, and without commensurate , consequently, to the practical possibilities of medicine.

Liability for fault has its foundation in the failure to observe both general rules of conduct, aimed at preventing damage events, and the common rules of "diligence",

[70] Fiori A, I1 criterio di probabilità nella valutazione medico-legale del nesso causale, Riv. It. Med. Leg. XIll,1991.

"expertise" and "prudence", and finally of laws, regulations, orders or disciplines, the correct observance of which would avoid the damage.

In order for a behavior to be imprudent and negligent, it must presuppose the predictability and predictability of the offense that occurred. It is therefore necessary to establish whether the event was avoidable or preventable by observing the rules of conduct and the rules.

The jurisprudence, however, has used the criterion in question only limited to "generic fault", that is, the type of fault that is based on the non-observance of the three common rules of conduct, consisting of professional "diligence", "prudence" and "expertise".

Neglect means the lack of diligence that is required of normal man, insufficient attention, lack of commitment, superficiality.

Imprudence consists in the realization of a positive activity that is not accompanied, in the special circumstances of the case, with the precautions that ordinary experience suggests to employ to protect the personal and others' safety.

It takes the form of a rash action that goes beyond the limits of normal prudence.

For there to be inexperience, the simple deficiency of a professional culture or of a specific technical skill and experience is not enough, without the need for awareness. If awareness exists, in addition to the imprudence of venturing into activities for which you know you are not suitable, even the potential malice may arise. Unskillfulness must be understood not only as a violation of particular norms concerning the exercise of certain arts or professions but also in the defect of that

minimum skill required in the exercise of a special task or function. They believe Fiandaca and Musco[71] should not overestimate the difference between the normative qualifications in question because what matters is that we can identify the rule of conduct violated in practice and whose observance would have avoided the event.

The specific fault is recognized in the non-observance not of rules of common experience (as is typical of generic guilt), but of specific provisions, constituted by laws, regulations, orders and disciplines coming both from public authority and from private general or even special character.

The cardinal of responsibility for fault lies, classically, in the predictability of the event, outside of which a guilty judgment can not be conceived, because in relation to the possibility of foreseeing what is not foreseeable, it can not be attributed to the agent that he did not take a different course to avoid producing the event. Otherwise, responsibility for fault would result in objective responsibility, undermining the ethical foundation of criminal law.

Anything that lies beyond predictability is therefore part of the fortuitous, even if it is connected to the action / omission by a causal link of materiality. This traditional approach, however, is not fully shared by the criminal doctrine.

The penal and civil judicial aspect of technical-professional responsibility presupposes the actual or presumed recurrence of damage to the person, for which the productive misconduct of the harmful event of medical-legal importance, and therefore of criminal and civilly relevant responsibility, necessarily implies an

[71] Fiandaca G, Musco E, Diritto penale, parte generale, Zanichelli ED., Bologna 1989.

incongruous technical moment, a mistake, a term which, should not be understood only in its episodic signification of result of inadequate behavior, referable now to lack of knowledge or culture, now to reckless or insufficient application of diagnostic methods, techniques, therapeutic guidelines that are part of the consolidated baggage of medical culture. The technical failure can mature at any moment of the medical act: in the diagnostic phase, where however it must be evaluated balanced between the double alternative risk of a hasty diagnosis, which can lead to an ineffective or harmful treatment, and a lack of diagnosis, expressive (liability for omission) of inertia; in the therapeutic phase, which may lead to errors, both in terms of the choice of therapeutic methods that are sometimes harmful and in any case inappropriate, even if perfectly selected and implemented; in the phase of the execution of the selected therapeutic activities: execution that may be imperfect in itself, or in relation to the subject that suffers its effects. The most typical hypothesis of the responsibility is that which is realized in the culpable realization, through action or omission, of a damage to the patient (injury or death) foreseeable and avoidable with a scientifically correct behavior always existing between anomalous conduct and concrete event occurring a precise relationship of cause to effect, a link of material causality.

From a strictly penal point of view, the consequences of the erroneous conduct of the health professional, if productive of culpable personal injury or death, are foreseen and configured in the context of crimes against life and personal safety as "personal injury" (Article 590 f the Criminal Code) and / or "culpable homicide" (Article 589 of

the Criminal Code), of which the doctor, in the event of failure to give a favorable result, responds precisely as guilty, where the culpability of the extremes occurs.

In other words, the doctor who causes, by his action or omission, an aggravation of the patient's pathological condition or a physical or psychological damage of a different nature, will respond to culpable personal injury; the doctor who erroneously determines death by induced aggravation of the illness that is the subject of the treatment, or for another reason, may be responsible for manslaughter.

Evidently, the personal injury or death of the patient must be linked to the conduct of the physician through the dual nexus of psychological causality and material causality.

It is necessary, that is, that the erroneous behavior of the doctor is ascribable to fault in the precise terms that are proper tho juridico-psychological figure; that, secondly, the event descends with an uninterrupted causal link between the erroneous medical behavior and not from contingencies that are intrinsic to the mere pathological trend or from completely unrelated causes.

The link of psychological causality is present when the medical error (resulting from inexperience, negligence, imprudence and not by chance or force majeure) gives rise to humanly and scientifically foreseeable and preventable consequences, in fact, with that commitment to conduct that law imposes on any citizen in the fulfillment of any act of life.

The anomalous moments of the conduct that give rise to the fault, as already mentioned, are alternately and synthetically attributable, therefore, to: imprudence,

negligence, inexperience, non-compliance with dereliction, regulations, orders and disciplines (Article 43 of the Italian Criminal Code).

While the imprudence and negligence resulting from substantial negligence on the part of the doctor of essential duties of professionalism towards the patient, such as to induce now excess of confidence, now hurriedness, now carelessness, attitudes all unrelated to the proper behavior, to the due adhesion to ethical-social and humanitarian principles that more than any other the doctor should feel; instead, the unskillfulness descends from the lack of knowledge of the technical problem that the doctor is called to resolve, which may derive from a lack of culture or dexterity, from ignorance attributable to lack of preparation, updating, experience.

The medico-legal investigation in the case of injury or culpable homicide is therefore based on:

- assessment of the technical-professional behavior supposed to be erroneous, also in light of the predictability of the event;
- definition of the event in medical-legal terms (very slight, slight, severe or very serious injury);
- reconstruction of the material causal link.

In evaluating the conduct, the valuation process must take into account, in addition to the mere erroneous moment, the complex of circumstances in which the error occurred; and in particular the set of professional characteristics of the doctor facing the entity of the task to which he is called, of the peculiarity of the pathological condition to be diagnosed or treated - which, if extremely complex, can more easily

generate an erroneous attitude - of the characteristics of more or less pronounced emergency in which the medical act is carried out, which, if experienced in situations of extreme discomfort and in any case of necessity, if productive of failure, must in any case be subsumed in a particular light also due to some reflections peculiar to the penal code; that affect responsibility (force majeure, state of necessity, etc).

The civil assessment of professional liability leads to the doctor's misconduct in the framework of the obligation to compensate for the damage, which occurs when it is carried out in the patient:

- unjust damage (iniuria datum) produced by illicit fact: inexperience, imprudence, negligence (Article 2043 of the Civil Code);
- a harmful event deriving from a breach of the contract of care for failure or defect of the doctor's commitment to his obligation to operate well.

In the first case, it deals with the issue of non-contractual liability, in the second case with regard to contractual liability.

From a procedural point of view, the two forms of responsibility can be invoked separately or in competition with one another, depending on the characteristics of the relationship.

Some particular issues, of great scientific and practical relevance, deserve to be briefly mentioned on the subject of the medical responsibility of the doctor: first of all, the complexity of the professional activity carried out in the hospital and which requires the participation and the competition of many subjects, for which it is invoked, particularly in matters of civil law, a hierarchical responsibility that

redirects the primary or the head of the team, if only for defects of choice and supervision of collaborators (culpa in eligendo and / or in guarding); and sometimes (more and more frequently), calls into question the structure and its administrative and / or technical managers, for organizational defects, modernization of diagnostic or therapeutic means, negligence of hygienic, radioprotective measures, etc.

Another aspect of extreme delicacy is that concerning the exercise of some specialized activities or the execution of particular services that, not solicited by therapeutic urgency, are instead carried out in order to obtain the applicant subject to an objective not motivated by true pathological indications and own, directed instead to satisfy the aspiration to a quality of life considered more pleasant and desirable.

In such cases, where harm occurs, it is debatable to the physician almost as a matter of objective responsibility.

In this regard, it is hardly necessary to remember that the medical service, as it is properly understood, does not produce a result obligation, but simply an obligation of behavior and of means, which means and postulates the commitment to operate in a scientific way more correct and theoretically more appropriate to produce the desired positive effect, which may however be lacking not only due to intrinsic performance defect but also due to the more or less unpredictable intervention of negative factors inherent in individual reactivity, or for the occurrence of complications or sequels that are practically unimaginable or predictable.

The spread of the medical liability of the doctor, which implies, if established, the compensation of the damage suffered by the patient, has largely produced the need

for the doctor, especially if usually dedicated to risk interventions, a large private insurance coverage for damage to customers.

For their part, hospitals are required to take out insurance policies to cover civil liability.

Failure by the physician of the principles of professional ethics, collected in the Code of Medical Deontology (2014), involves a procedure and an eventual disciplinary sanction, contemplated by the art. 3 of the Law of 13 September 1946, n.233, and exercised by the Board of Directors of the Provincial Order of Physicians and Surgeons.

Depending on the severity of the transgression or the reflection of a possible criminal conviction, the sanction may consist of the warning, the censorship, the suspension, the radiation from the professional register.

Please note that there are two successive degrees of judgment, at the Central Commission (art.5) and the Court of Cassation in Joint Sections.

Disciplinary responsibility derives from abuse or failure in the exercise of the profession or in any case from unbecoming facts for professional dignity, whether they are considered or not in the code of medical deontology.

The responsibility of the public health officer deserves an analysis that considers the health care in its quality as a structured or in agreement (by the NHS or other state and para-state institutions).

Apart from the commission of serious individual errors, the responsibility of the employee generally develops within the framework of the evolved articulation of the

health situation, especially hospital, which activates a plurality of interventions and moments, on each of them (Article 2055 of the Civil Code) still weigh the same burdens of conduct, also in terms of relationship with the patient and informed consent, which however develop in sequences and procedures so tight that often nullify an objective analysis in terms of detecting the eventual phase, moment, subject or subjects to attribute the failure or the transgression.

The "Consensus Guidelines Document"[72], elaborated by the EALM Working Group on Medical Malpractice includes a step-by-step illustrated explanation of approved Flow Charts, articulated in 18 sequential steps and comprehensive of both Methods of Ascertainment and Evaluation Criteria.

In particular, as regards cases of alleged medical professional responsibility for which an autopsy is scheduled, a series of items have been described regarding the methods of ascertainment on corpses.

Although regulations and operational practices are heterogeneous in all the countries considered, the method of ascertainment is the same, including examination of clinical and documentary data, execution of autopsy and possible further analyses.

These Guidelines sustain that prior to autopsy, several types of radiological investigations may be performed (X-ray, computed tomography, nuclear magnetic resonance). According to the case, it may be advantageous to take swabs for microbiological or genetic studies, prior to forensic autopsy.

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[72] Ferrara SD, Baccino E, Bajanowski T, Boscolo-Berto R, Castellano M, De Angel R, Pauliukevičius A, Ricci P, Vanezis P, Vieira DN, Viel G, Villanueva E, The EALM Working Group on Medical Malpractice. Malpractice and medical liability. European Guidelines on Methods of Ascertainment and Criteria of Evaluation. Int J Legal Med (2013) 127:545–557

In fact, during the last decade, studies have intensified with the aim to show the utility of imaging also in cases of non-traumatic death. In particular, many studies have been conducted on cases of deaths occurring in hospital settings and if they were less correlated with presumed malpractice.

Due to claims against hospitals and doctors, the number of autopsies performed in suspicion of medical malpractice is increasing[73,74], especially in surgery, the discipline with most accusations. In about two-thirds of case in Germany and the UK, the preliminary investigation can terminate with the autopsy[73,74].

[73] Madea B, Preuß J, Medical malpractice as reflected by the forensic evaluation of 4450 autopsies, Forensic Sci. Int. 190 (2009) 58–66.

[74] Start RD, Cross SS, Pathological investigations of deaths following surgery, anesthesia, and medical procedures, J. Clin. Pathol. 52 (1999) 640–652.

MATERIALS AND METHODS

In this review, we examined if the non-invasive or minimally invasive autopsy methods could replace conventional autopsy in cases of death related to suspected malpractice.

We searched the main databases, including PubMed Central, Medline, Web of Science, Scopus and Cochrane.

The search terms included the following elements: autopsy, imaging, malpractice.

The last review of the research was carried out in September 2018.

All searches in the databases together gave us 1166 articles that matched the search criteria, published from 1990 to September 2018.

After the initial screening in order to exclude duplicate sources and reviews, the articles were examined according to the following inclusion criteria:

- studies comparing the diagnostic performance of non-invasive or minimally invasive autopsy methods to that of the reference standard in cases of alleged malpractice;
- inclusion of case reports, series of cases, or retrospective studies;
- performing a conventional autopsy after post-mortal imaging;
- data deriving from the conventional autopsy for comparison;

- availability of clinical data, both instrumental and not, with to compare the results of post-mortem imaging.

Subsequently, the articles that did not meet the inclusion criteria for the purpose of this review were excluded, based on the titles of the articles and abstracts. Afterwards, the available full texts of the remaining articles were searched and evaluated and, therefore, those that fully met the inclusion criteria were selected. Of all the articles present, eight were considered suitable for the purpose of this work.

Despite the community's interest in the potential role of post-mortem imaging, the data on the applicability of these diagnostic techniques to cases of presumed malpractice have not been sufficiently solid to confirm the equivalence or the superiority of the virtual autopsy compared to conventional one.

Four articles concern single-case reports. [75,76,77,78]

Only more recently had been conducted several studies that included a more numerous series of cases[20,79,80,81].

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[75]Kominato Y, Fujikura T, Hata Y, Matsui K, Takizawa H. (2004). A case of postoperative hemorrhage after a hysterectomy in which a bleeding point of the left uterine artery was identified by postmortem angiography. Leg Med (Tokyo). Jul; 6 (3): 187-9.

[76] Tajima Y, Takagi R, Kominato Y, Kuwayama N. (2007) A case of iatrogenic cerebral infarction demonstrated by postmortem cerebral angiography. Legal Medicine 9 326-329.

[77]Schro¨der AN, Heinemann A, Nushida H, Sperhake JP. Fatal pneumoperitoneum following endoscopic retrograde cholangiopancreatography confirmed by post-mortem computed tomography. Forensic Sci Med Pathol (2015) 11:460–463.

[78] Vilariño Villaverde R, Bruguier C, Zerlauth JB, De Froidmont S, Grabherr S. Tearing of the left iliac vessels in lumbar surgery revealed by multiphase post-mortem CT-angiography (MPMCTA). Legal Medicine 20 (2016) 44–48.

[79] Heinemann A, Grabherrb S, Dedouitb F, Woźniakc K, Fischerd F, Wittige H, Grimma J, Vogela H, Technical Working Group on Post-Mortem Angiography Methods (TWGPAM)Journal of Forensic Radiology and Imaging (2017). The impact of multiphase post-mortem CT-angiography (MPMCTA) for investigating fatal outcomes of medical interventions.

Among these, in two studies[20,81] conducted by the authors themselves, 9 clinical cases were analyzed for each study, three of which seem to have been reported in both works.

The cases included in the selected studies concerned cases of death in subjects aged 15 years to 94 years, most of them female.

In six of the eight selected articles, the postmortem non-invasive autoptic technique investigated was angiography, in one study only CTPM was studied, while in one study both post-mortem radiological techniques were used[77].

[80] Heinemann A, Vogel H, et al. Radiol Med (2015). Investigation of medical interventions with fatal outcome: the impact of post-mortem CT and CT- angiography. 120 835.

[81] Zerlauth JB, Doenz F, Dominguez A, Palmiere C, Uske´ A, Meuli R, Grabherr S (2013) Surgical interventions with fatal outcome: Utility of multi-phase postmortem CT angiography. Forensic Science International 225 32–41.

RESULTS

An important fact that emerges from the study of the scientific literature concerns the applicability of these imaging techniques in the evaluation of death cases related to presumed medical errors.

Some studies have verified the usefulness of adopting the aforesaid post-mortem imaging techniques before proceeding with the traditional autopsy to verify the existence of profiles of professional responsibility in the work of the Sanitary in cases of exitus of patients undergoing medical treatment. In these studies the results obtained were compared following a virtual autopsy and traditional autopsy, finding a substantial correspondence of the same.

In the two studies conducted by Heinemann et al.[79,80], in which a total of 12 cases were discussed, emblematic situations were analyzed regarding sudden and sudden deterioration of clinical conditions resulting in the death of patients undergoing surgery, even minimally invasive, delayed or omitted. diagnostic and / or therapeutic interventions, deaths after resuscitation maneuvers (suspected of delayed action, inadequate performance, in particular problems with intubation)[79].

In the case of patients who died during surgery or after a short time from the same it is essential to determine if the cause of death is attributable to a medical error, to a complication of the surgical procedure independent by the work of the doctor or is not at all related to the intervention.

With PMCTA it is possible to identify the presence of bleeding and in some cases also the exact source of bleeding[20] in cases of abdominal surgery it allows to identify

signs of complications related to laparoscopic and laparotomic procedures, such as anastomotic dehiscences, intestinal ischemia, paralytic ileus, infections of surgical wounds with abscess formation; in the field of cardiac surgery it can show coronary perforation, cardiac tamponade, aortic dissection; it may also provide evidence of indirect signs of multi-organ dysfunction as a generalized soft tissue edema and pleural and peritoneal effusion[80].

Another circumstance in which the use of PMCT and PMCTA has been studied concerns the presumed wait-and-see attitude of health workers who, in particular cases, consider it appropriate to subject the patients to instrumental examinations in order to arrive at a pre-operative diagnosis, rather than proceeding to an immediate surgical exploration. In these cases it was possible to compare instrumental findings prior to death with those obtained following a virtual autopsy.

Cases of incorrect intubation, such as esophageal malposition, bronchial intubation, esophageal or tracheal perforation, but also dislocation of the trachea have also been reported. It was possible to detect the presence of gas in abnormal sites (in cervical tissues and in the mediastinum) after tracheotomy. Although it was difficult to identify the source of gas / air leakage, particularly in the thoracic and abdominal cavity, PMCT still allowed to detect the presence of pneumothorax after jugular and subclavic puncture[73] .

Data reported in the most recent medico-legal literature indicate that postmortem angiography has significantly improved the diagnostic potential of detecting bleeding

sources in cases of acute hemorrhages with fatal outcomes[82].

Palmiere et al.[20] investigated the diagnostic value of MPMCTA compared to conventional, ante-mortem CT- scan, CTA and DSA in the detection and localization of the source of bleeding in cases of acute hemorrhages with fatal outcomes.

On 170 medico-legal cases in which was performed multi-phase post-mortem CT-angiography was conducted a retrospective selection. These victims died of a hemorrhage after they had a radiological exam that should have identified the source of bleeding.

In eight of nine cases, the applied technique of MPMCTA was able to detect and localize the exact source of bleeding whereas conventional autopsy was able to provide conclusive information in only three cases. Injuries of large vascular structures can be diagnosed during an autopsy whereas small vessel injuries may only be speculated due to the presence of surrounding hematomas. In our study, the specific diagnosis of small artery rupture was only possible through MPMCTA.

Only in one case the origin of bleeding was not clearly identified either by clinical radiological investigations and post-mortem investigations. The authors hypothesized that the hemorrhage was probably due to the laceration of a small vesical vessel, most likely a branch of the superior vesical artery, or that bleeding was not active when the antemortem radiological investigations was performed.

In some specific (and not infrequent) medico-legal situations (e.g., when the affected

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[82] · Ruder D, Ketterer T, Preiss U, Bolliger M, Ross S, Gotsmy WF, Ampanozi G, Germerott T, Thali MJ, Hatch GM, Suicidal knife wound to the heart: challenges in reconstructing wound channels with post-mortem CT and CT-angiography, Legal Med. (Tokyo) 13 (2011) 91–94.

vessels are very little or are located in difficulty accessible anatomical areas of the body), to identify the source of hemorrhage may seems almost impossible. The detection of the vessel causing the bleeding may represent the key element in these cases and the most important information requested by judicial authorities.

Zerlauth et al[81]. conducted a study on a collection of 180 cases that were examined using the protocol described by Grabherr et al. in 2011[16], including cases due to suspicion of a medical error, for which the assignment for a medico-legal examination was given by the prosecuting attorney. MPMCTA was demanded by the forensic doctor in charge of the case due to suspicion of vascular lesions.

All study data were analyzed retrospectively studying all findings from the antemortem clinical data, the postmortem radiological report and the medico-legal autopsy reports.

In eight of the ten cases, death was directly (exsanguination) or indirectly (aspiration of blood) due to hemorrhage. This is in line with reports in the literature, as postoperative hemorrhage is one of the most common complications after surgical intervention[83]. The autopsy was only able to localize the sources of bleeding in three cases. MPMCTA allowed the detection of the exact source of bleeding in nine of ten cases. In a case, both MPMCTA and antemortem clinical angiographic methods failed to detect the source of blood. In this case, the authors considered that the presence of a large volume of intra-abdominal fluid (about 1300 ml) caused an increase in intra-abdominal pressure, which blocked the bleeding before the

[83] Di Nunno N, Luigi V, Viola L, Francesco V, Epidemiological case survey of medical malpractice in some medical and surgical specialties, Forensic Sci. Int. 149 (2005) 139–142.

radiological examination.

The study also describes a case in which this technique was fundamental to investigate the patient's vascular anatomy because there was an anatomical variant of the splenic splitting of the splenic artery, identified only by MPMCTA. In fact, with the conventional autopsy, this varied anatomy would have been difficult to detect.

Kominato et al[75] reported a case of fatal postoperative hemorrhage caused by failure to ligate the left uterine artery during a hysterectomy in a 42-year-old woman, as demonstrated postmortem by conventional autopsy methods and confirmed by angiography.

Tajima el al.[76] reported a case of a 37-year-old man with an intracranial meningioma which compressed the right frontal lobe, to be treated with preoperative embolization and resection.

During the embolization an excess amount of the embolization agent was accidentally injected. X-ray monitoring showed that contrast medium flowed into the right internal carotid, anterior and middle cerebral arteries. The patient died 47 days after the operation without improvement of the coma. A medicolegal autopsy was performed to clarify if malpractice had occurred during the embolization procedure.

Postmortem angiography was performed, before conventional autopsy, by injection of radio-opaque contrast medium in both common carotid arteries. At the skull section, the left cerebral hemisphere was found to be rather necrotic, and extravasation of the contrast medium in the vessels was observed. The right hemisphere was widely necrotic and fragile, in the absence of contrast medium. The

CT scan, performed after formaline brain fixation, computed tomography showed that the arteries of the left cerebral hemisphere were almost completely filled with the radiopaque medium, while only a small part was filled in the right hemisphere. This suggested that an almost complete occlusion of the right internal carotid artery occurred. The embolizing agent injected into a branch of the right central meningeal artery would have been able to embolize the right internal carotid artery and its branches, causing infarction of the right cerebral hemisphere, followed by edema, perfusion impairment and brain necrosis.

Vilarino et al.[78] treated a case of fatal iatrogenic laceration of the proximal portion of the left common iliac artery and left iliac vein during lumbar surgery in a 60-year-old woman suffering from symptomatic L5-S1 sciatica. The patient quickly developed intra-abdominal hemorrhage. The MPMCTA detected the bleeding source and the macroscopic examination of the lumbar section allowed the identification of the exact trajectory of the surgical instrument.

Schroeder et al.[77], however, described a case of a deceased 80-year-old woman after endoscopic retrograde cholangiopancreatography (ERCP). The PMCT demonstrated an impressive pneumoperitoneum and the diaphragm ascent, allowing to calculate the presence of a total volume of about 11 l of intraperitoneal air through volume rendering techniques. As demonstrated by autopsy, the pneumoperitoneum was caused by anterior perforation of the duodenal wall.

DISCUSSION

Several advantages associated with the use in cases of judicial interest of the autoptic techniques described above has been showed by the analysis of the international bibliography.

First of all, it has been found that the documentation and analysis of the post-fatal characters with CT are independent, objective and such as to produce improvements in the quality of investigations of forensic pathology.

The acquisition of images and subsequent processing require much less time than the complete autopsy. The virtual autopsy can also decrease the time necessary for the coroner to perform a traditional autopsy, because he would be previously informed of the most significant findings to be evaluated.

Another important aspect concerns data retention. In fact, autopsy specimens, such as tissue samples, can not be stored indefinitely, but digitally acquired data can be easily archived and then consulted whenever new medico-legal issues arise and can also be sent to other experts[9].

Often, forensic doctors are appointed as advisors to the A.G. for the examination of non-recent cases. Since exhumations and cremations are more and more frequent, the usefulness of having radiological data able to provide essential information to help forensic pathologists in responding to questions that may arise during the judicial process, sometimes different, is ineffective. years after the autopsy. PMCTA provides permanent digital data that can be used as evidence, even many years after the events, for reporting diagnostics, analysis or audits (so-called virtual exhumation) at any

time[84,85].

Therefore, it is very important to develop standardized techniques for post-mortem radiological investigations, as a statement of guidelines for the interpretation of radiological data appears deeply important. Evaluating the sensitivity of the post-mortem radiological investigation is also a part of this process.

With the PMCT it is possible to evaluate the size and weight of the organs, to highlight pathological conditions, neoformations and cysts, to deepen the study of the normally poorly examined districts in order not to mutilate the body, such as the extremities, the musculoskeletal system and the splanchocranium. It is also possible to identify conditions such as subcutaneous, intravascular or intrapericardial emphysema not visible at macroscopic examination, as well as intracavitary lesions, including hiatal or inguinal hernias, difficult to detect with macroscopic examination but easily recognizable with PMCT[35].

Anyway, with the post-mortem CT scan it is not possible to evaluate fundamental elements such as the rigor mortis, the organ color, the vitality of lesions and, moreover, there are important diagnostic difficulties related to the limited visualization of the vascular system and of soft tissues. For this reason the use of post-mortem CT angiography was introduced[86].

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84 Morgan B, Initiating a post-mortem computed tomography service: the radiol- ogist's perspective, Diagn. Histopathol. 16 (2010) 556–559.

85 Saunders, Morgan B, Raj V, Rutty G, The role of post-mortem computed tomography in coronial autopsy practice; the Leicester experience, RAD Mag. 37 (2011) 19–20.

86 Grabherr S, Grimm J, Dominguez A, Vanhaebost J, Mangin P. Br J Radiol. April 2014; 87(1036). Advances in post-mortem CT-angiography.

In Bove et al.[87,88] study, was highlighted the importance of an appropriate and clear high quality documentation so the autopsy reports should provide objective medical information in a suitable format for the attending physician, for the patient's medical record and for the other concerned staff physicians, but also for the other health care professionals, and for the deceased's family.

Bodies which come from an hospital usually show many signs of medical interventions, for example vascular puncture devices, medical drains, and surgical materials.

A native CT scan performed before any manipulation of the body allows documentation of the presence and location of medical materials from the surgical intervention or resuscitation attempt, such as venous catheters, compresses, drains, etc.

While the position of some materials, such as catheters and drains, can be determined by conventional autopsy, other materials, such as the microcoils used for intravascular embolization, are more difficult to detect. It is also difficult to document the position of intra-ventricular drains using conventional methods.

For these reasons, even if MPMCTA is a very good technique for investigating cases of suspected medical error, it is still important to perform a conventional autopsy too. In facts, it will only the combination of the two techniques that will be the new gold

[87] Bove KE, Iery C, Autopsy Committee, College of American Pathologists, The role of the autopsy in medical malpractice cases. I: A review of 99 appeals court decisions, Arch. Pathol. Lab. Med. 126 (2002) 1023–1031 (Review).

[88] Bove KE, Iery C, The role of the autopsy in medical malpractice cases. II: Contro- versy related to autopsy performance and reporting, Autopsy Committee, College of American Pathologists, Arch. Pathol. Lab. Med. 126 (9) (2002) 1032–1035.

standard, as it was already suggested by Jeffery et al.[89]

The use of autoptic imaging techniques such as PMCT and PMCTA, always followed by traditional autopsy, can significantly improve the diagnostic effectiveness in post-mortem investigations of presumed medical malpractice. However, its role in the analysis of mortality in the context of clinical risk management is still under investigation.

There are few standards and guidelines; moreover the findings need to be interpreted together by experienced forensic pathologists and radiologists. Therefore, at least for the moment, all findings should be confirmed using conventional autopsy.

These techniques provide data that can help to increase patient safety, improving also the quality of care and reducing surgical risks.

After surgery, it's easy to found large zones with hemorrhagic infiltration with modified anatomy due to incisions, that often make dissection and evaluation of autopsy findings difficult.

Using post-mortem radiology techniques, these conditions can be studied in a minimally invasive way before autopsy, and may facilitate the execution of the traditional autopsy examination.

Some authors have thought to teleradiology networks, to allow the study of special cases also by external specialists, with the aim of providing a second opinion for the

[89] Jeffery A, Raj V, Morgan B, West K, Rutty GN, The criminal justice system's considerations of so-called near-virtual autopsies: the East Midlands experience, J. Clin. Pathol. 64 (2011) 711–717.

local coroner, like already proposed by Robinson[90] and Rutty[91].

Studies in the literature have been conducted on numbers that are too small to obtain scientifically relevant data for solids statistical analysis; therefore these results should be confirmed in the future on a larger sample, which could be obtained through the conduct of multicentric studies. It is also desirable to standardize post-mortem radiological techniques, as well as to develop guidelines for the interpretation of radiological data.

[90] Robinson C, Eisma R, Morgan B, Jeffery A, Graham EA, Black S, Rutty GN. Anthropological measurement of lower limb and foot using multi-detector computed tomography, J. Forensic Sci. 53 (2008) 1289–1295.

[91] Rutty GN, Robinson CE, BouHaidar R, Jeffery AJ, Morgan B. The role of mobile computed tomography in mass fatality incidents, J. Forensic Sci. 52 (2007) 1343–1349.

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