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FORENSIC RADIOLOGY SPECIAL FEATURE: REVIEW ARTICLE

Advances in post-mortem CT-angiography

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ABSTRACT

Performing a post-mortem multidetector CT (MDCT) scan has already become routine in some institutes of forensic medicine. To better visualize the vascular system, different techniques of post-mortem CT-angiography have been explored, which can essentially be divided into partial- and whole-body angiography techniques. Probably the most frequently applied technique today is the so-called multiphase post-mortem CT-angiography (MPMCTA) a standardized method for investigating the vessels of the head, thorax and abdomen. Different studies exist, describing its use for medicolegal investigations, and its advantages as well as its artefacts and pitfalls. With the aim to investigate the performance of PMCTA and to develop and validate techniques, an international working group was created in 2012 called the "Technical Working Group Post-mortem Angiography Methods" (TWGPAM). Beyond its primary perspective, the goals of this group include creating recommendations for the indication of the investigation and for the interpretation of the images and to distribute knowledge about PMCTA. This article provides an overview about the different approaches that have been developed and tested in recent years and an update about ongoing research in this field. It will explain the technique of MPMCTA in detail and give an outline of its indications, application, advantages and limitations.

The use of multidetector CT (MDCT) in post-mortem investigations is becoming more and more common in forensic institutes. The first post-mortem CT (PMCT) was reported in 1983.[1] Since then, the numbers of PMCT examinations have increased significantly through the past years[2–11] to the point where it has now become a routine investigation in several medicolegal centres all over the world. This may be because of the fact that the handling of a CT scan is relatively easy, data acquisition is rapid and maintenance costs are affordable for some institutes of legal medicine. Several studies have been performed with the aim of investigating the diagnostic value of MDCT compared with conventional autopsy.[8,9,11] It was even proposed that PMCT could replace conventional autopsy in certain cases.[12,13] In fact, the role of PMCT as an adjunct to or a replacement for autopsy is discussed vigorously, and opinions are divided on the subject. There are several obvious advantages of MDCT over conventional autopsy: it is a rapid and easy way to look inside the body and document findings. Additionally, it offers the opportunity to re-read data at any time, even after cremation or burial of the body. However, there are also limitations. Although native or unenhanced MDCT can show major vascular lesions such as aortic rupture,[14] its most important weakness is its limited soft-tissue contrast and low ability to visualize the vascular system. To overcome this problem in clinical MDCT for living patients, a contrast agent is used. Following this example, researchers started using contrast media in PMCT, and PMCT-angiography (PMCTA) was introduced.[15] In recent years, the number of publications concerning PMCTA has increased significantly, signalling that research teams all over the world started to develop techniques for the injection of contrast agent into the body of the deceased and thus perform post-mortem angiography (PMA).

CLASSIC METHODS FOR POST-MORTEM ANGIOGRAPHY

The idea to inject a contrast agent into the vascular system is very old. Its roots go back to the beginning of the 16th century, when scientists such as Leonardo da Vinci and Jakobus Berengius studied the human body. To investigate the interior of hollow anatomical structures, they produced wax casts of the heart chambers and the cerebral ventricles by using maggots to rid their casts of the surrounding tissues.[16,17] Finally, during the 17th and 18th centuries, the first direct vascular injections were performed by pioneers such as de Graaf, Ruysch, Lower and Virchow.[16,17] The resulting vascular casts showed impressive details and were used to study the anatomy of the vascular system. These classic methods were discontinued after the discovery of X-rays, which allowed visualization of the injected vessels without destroying the surrounding tissue by adding radio-opaque materials to the injection liquids. During the first half of the 20th century, numerous methods and injection materials existed, and all kind of organs have been investigated to understand their vascular anatomy. According to the injection materials used, the techniques performed can be divided into six groups:[17] (I) corpuscular preparations in gelatine or agar, (II) corpuscular preparations in watery solution, (III) oily liquids, (IV) hydrosoluble preparations, (V) casts, and (VI) miscellaneous. All of these techniques had their proper advantages and pitfalls. Some of them, especially the casting methods, were used regularly, whereas others have been described only once or twice in literature. The most frequently stated techniques were those using barium sulphate in gelatine or agar[18] or in water[19] as well as casting techniques using a silicone rubber and lead oxide.[20] Unfortunately, most of the classic methods were applicable only to single organs, especially the casting techniques. There are only a few publications describing angiographies of a whole human body, mostly on human embryos and foetuses[21] or newborns[22] immediately after death.

Both the applied injection material and the technique used to inject the liquids varied between the different methods. Most methods used simple manual injection by means of a syringe to introduce the contrast agent into the vascular system. Although there existed many recommendations on how to perform the perfusion in single organs,[16] nearly no literature existed concerning perfusion in whole bodies. An exception is the article by Stoeter and Voigt[22] that describes a radiologically controlled discontinuous injection of the contrast agent, with imaging performed during the intervals. Using this approach, the filling of the vascular system could be observed.

By the end of the 20th century, the use of PMA had nearly ceased without any obvious reason. Articles appeared only rarely, describing the investigation of specific parts of the vascular system such as oesophageal veins,[20] coronary arteries,[23] intracranial arteries[24] and spinal arteries.[25] After this time, the classic methods seemed to have been forgotten.

POST-MORTEM ANGIOGRAPHY GOES FORENSIC IMAGING—INTRODUCTION OF POST-MORTEM CT-ANGIOGRAPHY

With the introduction of MDCT into PM investigations and the goal to enhance the PMCT by contrast agents, new research started with the aim of combining PMA with PMCT. This is understandable, as clinical investigations show that the injection of a contrast agent increases the diagnostic sensitivity of MDCT. For example, in clinical practice, CT-angiography (CTA) is the most widely used method in the detection and localization of clinically active haemorrhages of an unknown source.[26] It is also the method of choice for the assessment of coronary artery disease in acute and chronic cases,[27] as it allows investigating the arterial lumen and vascular wall diseases. The first systematic research was started in 2004 in the Institute of Legal Medicine in Bern, Switzerland, in the context of the Virtopsy® project.[28] In 2005, Jackowski et al[29] reported preliminary results of a new technique of minimally invasive whole-body PMCTA using a cannulation of the femoral vessels on one side of the body and the injection of meglumine ioxithalamate as a contrast agent. At the same time and same place, first experiments started with a dynamic angiographic analysis of a whole body. The concept of these experiments was that to perform a PMCTA that resembles clinical CTA, conditions similar to *in vivo* conditions should be created. Form these hypotheses came the idea to establish a "post-mortem circulation", which should allow perfusion of the body.[30] A first feasibility study, performed on an animal model, showed the success of the concept in using diesel oil as a perfusate and a roller pump as a perfusion device.[31] Multiple imaging at defined intervals permitted a dynamic visualization of the arterial, parenchymal and venous systems. This technique was later on adapted on a human model by changing the perfusion liquid and the injection technique. The resulting technique was called "two-step post-mortem angiography",[32] as it consisted in the establishment of a PM perfusion as a first step and the injection of contrast agent with simultaneous image acquisition as a second step. This technique is also the first to be described in the literature as using a modified heart–lung machine as a perfusion device.

While Jackowski et al used an aqueous solution as an injection medium, the methods described by Grabherr et al[31,32] had in common an injection liquid that was oily. The use of an oily perfusate was chosen because that oily liquids have the ability to remain intravascular,[33] which makes them suitable while performing a perfusion without high loss of the perfusate into the surrounding tissue and without an oedematization of the latter.[34] Although these techniques provided excellent vessel visualization, they had their weaknesses. The major problem with techniques using oily injection liquids was the appearance of a discharge of the perfusate into the stomach and the intestine, which showed a clear locus minoris resistentiae.[31] This finding was not surprising given the combination of bacterial decomposition and autolytic activities that occurs in the gastrointestinal tract, which may lead to an early increase in vascular permeability in this region. The aqueous contrast agent solution used by Jackowski et al caused tissue oedema and artefacts in histological investigations, which rendered its application in medicolegal cases difficult. To overcome these problems, the two different approaches had been further developed later on. Jackowski et al[35] proposed to add a hydroscopic polyethylene glycol as a contrast agent dissolver,[34] and Grabherr et al[36] changed the viscosity of the oily perfusate and developed a new contrast agent for PMCTA.

Based on these researches, two of the most often used PMCTA techniques were established: multiphase PMCTA (MPMCTA) and PMCTA using aqueous contrast agent and polyethylene glycol. Only a few years later, active research in PMCTA started, also in England, where the techniques of targeted coronary angiography (TCA) were developed independent of each other in Oxford and in Leicester, as well as in Japan, where PMCTA using cardiopulmonary resuscitation (CPR) was established. Today, these techniques are the most commonly used and shall be described in more detail in the following sections.

TODAY'S MOST USED POST-MORTEM CT-ANGIOGRAPHY TECHNIQUES

Multiphase post-mortem CT-angiography

In the University Centre of Legal Medicine in Lausanne, Switzerland, a research group was created with the aim of further developing the technique of PMCTA. The idea was to define a standardized protocol for high-quality PMCTA, which should allow a better radiological interpretation of the resulting images, by reaching a complete filling of the vascular system and by decreasing artefacts caused by perfusion. At the same time, the technique should be easy and rapid to perform. This second aim should also be achieved by developing adequate material for the injection. As a result of this research, the technique of MPMCTA was developed and published for the first time in 2011.[36] In this study, 45 human corpses were investigated by PMCTA using different perfusion protocols, a modified heart–lung machine and a new perfusate for which the recently developed contrast agent Angiofil® (Fumedica AG, Muri, Switzerland)[37] was mixed with paraffin oil with a higher viscosity than the one used before (paraffinum liquidum instead of paraffinum perliquidum). In fact, a microscopic study[31] revealed that the oil blocks the capillary region, which is especially vulnerable to PM permeability, because of fatty embolism. However, the oil enters the venous system by passing through small arteriovenous shunts. The same mechanism is known and used in cancer treatment to separate tumours from their blood supply during chemoembolization.[38] The level of this microembolization depends on the viscosity of the oily perfusion. By increasing the viscosity of the perfusate, the mean weakness of the previous oily methods, the appearance of important extravasation in the gastrointestinal tract, has nearly disappeared. The research revealed two other important features necessary to perform high-quality PMCTA. Firstly, the need of high perfusion volumes and secondly, owing to the appearance of artefacts during PMCTA, the performance of several data acquisitions in succession, allowing the comparison of images between the different series. Therefore, the standard protocol of MPMCTA consists in the performance of one native CT scan followed by three angiographical phases. To interpret a finding as real, it has been proposed that the same finding should be visible in at least two of the three phases; otherwise, it should be interpreted as an artefact.

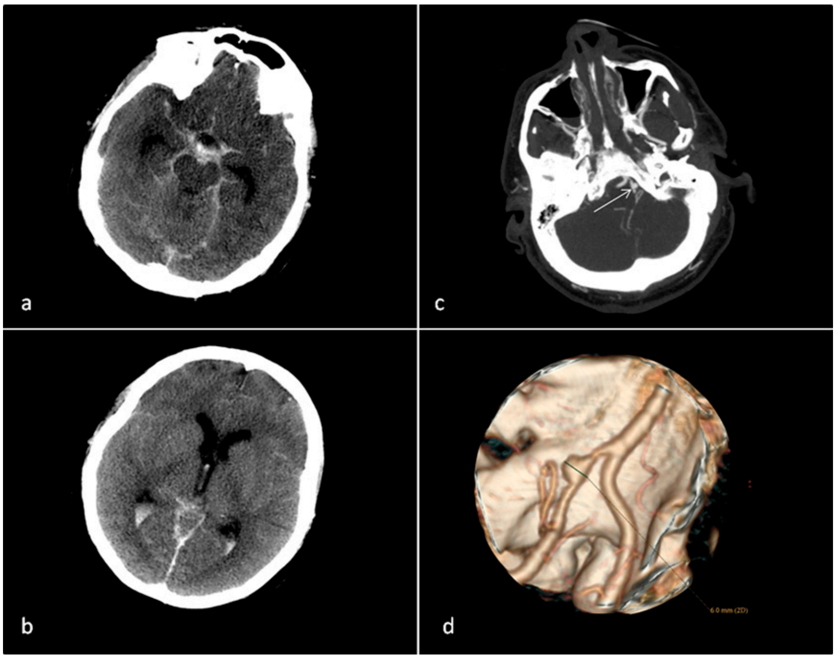
To perform the technique, the femoral vessels of one side of the body are freed from the surrounding tissue by using a cutaneous incision of about 5–10 cm. During the cannulation process, blood samples are collected in different tubes for toxicological and biochemical analyses. Once these preparations are complete, the PMCTA starts by injecting a contrast agent mixture composed of 6% of Angiofil and paraffin oil, using standardized injection parameters (injection time, pressure, volume and flow rate) for each angiographic phase. The injection is performed using a modified heart–lung machine or, as proposed in later articles, a Virtangio® perfusion device (Fumedica AG).

By using the technique of MPMCTA, the whole vascular system of the head, thorax and abdomen is visualized. The only exceptions comprise parts of the cerebral sinus and vessels, which are, in some cases, occluded by huge PM clots,[39] which can create artefacts. A recent study has shown that all artefacts observed after an MPMCTA are reproducible and stable in terms of their localization and type, making them relatively easy to recognize.[39] Understanding of these artefacts can avoid misinterpretation during the radiological evaluation and therefore increase the quality of the radiological interpretation.

To compare the performance of MPMCTA to conventional autopsy, a study was performed comparing radiological reports from PMCTA with reports from conventional autopsy for 50 forensic autopsy cases.[40] In this study, the findings described already for native CT and those after the MPMCTA were investigated separately, allowing a comparison of the diagnostic value of conventional autopsy, native CT only and native CT with MPMCTA. The findings were also divided according to their anatomical compartments (soft tissue, bone, organs and vascular) and the importance for the medicolegal interpretation of a case. The results showed that MPMCTA and conventional autopsy would have drawn similar conclusions regarding causes of death. Nearly 60% of all findings were visualized with both techniques. PMCTA demonstrated a higher sensitivity for identifying skeletal and vascular lesions. Conventional autopsy provided more information about organ morphology and pathology. By considering all findings regardless of tissue type and importance, MPMCTA and conventional autopsy demonstrated nearly the same sensitivity concerning the detection of findings. MPMCTA could increase the sensitivity of native CT scan from 65% to 80.9%, whereas conventional autopsy detected 83.1% of all findings. The results concerning findings which were classified as essential for solving the medicolegal case were more surprising: autopsy reported 77.2% and MPMCTA reported 93.3% of all findings. For this reason, it was concluded that MPMCTA is an extremely powerful and useful tool for PM investigations.

While the described study of Chevallier et al[40] was performed on all cases investigated in a medicolegal centre, without any inclusion criteria concerning the circumstances and cause of death, other studies have been carried out investigating different case groups for which a CTA would be indicated in a clinical setting: traumatic cases, in which a source of bleeding should be detected;[41] cases of death following surgical intervention;[42] and cases of cardiovascular disease.[43] These studies revealed that MPMCTA had a considerable diagnostic potential in detecting the sources of bleeding. It shows evident advantages over conventional autopsy, particularly when the affected vessels are of small calibre or are located in anatomical areas of the body that are difficult to access (Figure 1). By comparing MPMCTA with clinical antemortem CTA, it was proven that it is even more sensitive than clinical CTA in detecting involved vessels.[41] For this reason and because identifying the exact source of bleeding is often the major question in cases of fatal outcome of surgical intervention, the combination of MPMCTA with the autopsy was stated as the new gold standard for investigating cases in which a medical error may have occurred.[42] The visualization of bleeding sources and extravasation of contrast agent can also be used as a tool to visualize trajectories such as trajectories of projectiles in cases of lethal gunshots (Figure 2) or stab wounds in cases of sharp trauma.

Figure 1. Images obtained from a case of a 48-year-old male, found dead sitting on his sofa. Native post-mortem CT (PMCT) (a, b) shows subarachnoid haemorrhage in basal compartment (a) and in the ventricular system (b). Arterial phase of multiphase PMCT-angiography (c, d) reveals the source of bleeding originating from an aneurysm in the left vertebral artery (arrow in c). The three-dimensional-volume rendering reconstruction (d) better visualizes the aneurysm and measurement shows a diameter of 6 mm.



Also, for cases of sudden cardiac death, especially because of coronary heart disease, MPMCTA proved as a useful and promising technique (Figure 3). A recent study, performed on 23 cases, selected based on clinical history and the results of native PMCT, aimed to evaluate the diagnostic value of MPMCTA for investigating sudden cardiac deaths related to ischaemic heart disease.[43] According to this study, the images obtained from MPMCTA facilitated the visualization of coronary arteries and permitted the evaluation of stenoses and occlusions. It also helped visualize cardiac infarction as a so-called "pathological enhancement". In fact, by using the lipophilic contrast agent mixture, normal myocardium does not show any accumulation of contrast agent but, in cases of infarction, the myocardium is enhanced by the contrast allowing the recognition of the infarcted area. Compared with conventional autopsy, MDCT allowed a better assessment of coronary artery calcifications. The authors, therefore, concluded that MPMCTA is a reasonable tool to view the morphology of coronary arteries, rule out significant coronary artery stenosis, identify occlusions and direct sampling for histological examination. Another study, performed exclusively for identifying coronary thrombosis by MPMCTA, revealed that it was possible to identify old and fresh coronary thrombosis.[44]

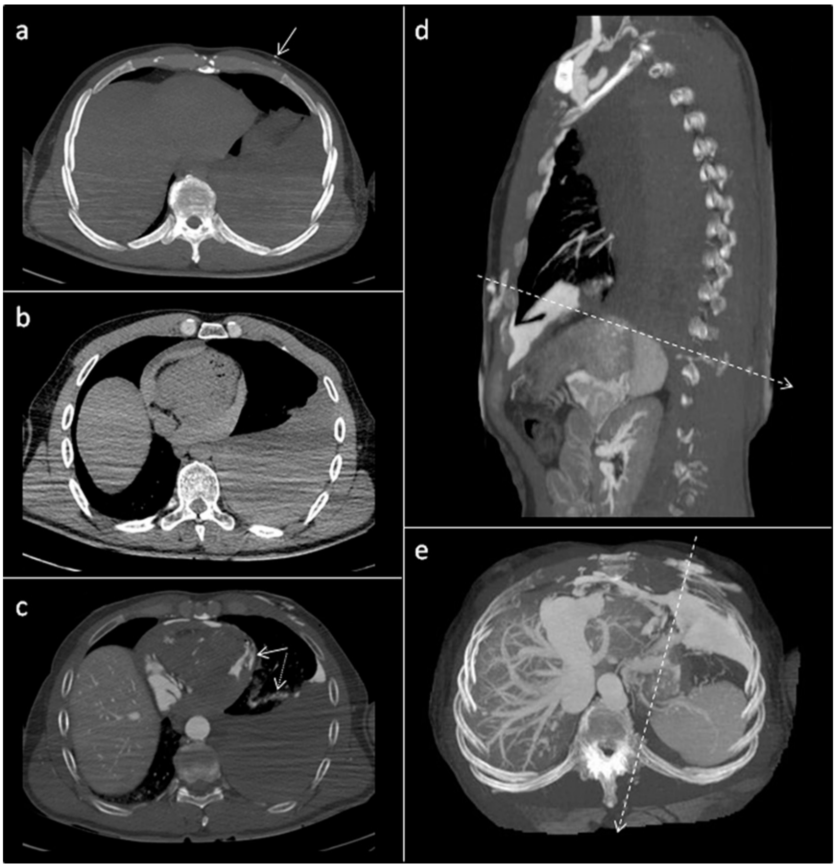
Post-mortem CT-angiography using aqueous contrast agent and polyethylene glycol

A few studies with small numbers of human and animal corpses or organs have addressed the possible use of contrast agents in watery solutions and polyethylene glycol (PEG). Jackowski et al used different mixtures of polyethylene glycol in porcine hearts[29,35] and in a human corpse.[45] They reported particular tissue enhancement properties possibly increasing diagnostic value of the method, while higher viscosity PEG solutions seemed to limit extravasation and overenhancement of various tissues. Doubts remain regarding histological and biochemical alteration in tissue containing lipid components, as PEG acts as a solvent for lipids. Also, the number of cases examined were too small to provide sufficient information for a thorough assessment of the method. Ross et al[46] compared mixtures of oily contrast agent in paraffin and water-soluble contrast agent in PEG solutions in 10 human cadavers. Although both contrast agents delivered comparable opacification of the vascular system, the lipophilic mixture showed extravasation in the intestinal tract; the hydrophilic contrast agent displayed a pronounced soft-tissue enhancement, comparable to that reported by Jackowski et al;[35] however, some artefacts were encountered, which could not be fully explained (*e.g.* overenhancement of neck muscles after failed resuscitation). Again, the number of cases seem too small to fully appreciate advantages and disadvantages of the method.

POST-MORTEM CT-ANGIOGRAPHY USING CARDIOPULMONARY RESUSCITATION

This technique for visualizing the vascular system was initiated in Japan, where PMCT is performed regularly in >20 000 cases per year.[10] It is used immediately after death, as a screening method for unusual causes of death in patients dying in emergency rooms. The high rate of PMCT may be argued by the fact that in Japan, owing to traditional reasons, the autopsy rate is very low. Instead, several Japanese hospitals conduct PMCT to have an idea of the cause of death. For the same traditional reasons, and because any surgical intervention such as the cannulation of vessels in a deceased patient is shunned, an even less invasive and simple technique, ideal for hospital application was sought. The solution for this problem should be the technique of PMCTA using CPR.[47,48] As stated in the literature, CPR can increase blood

Figure 2. A case of a 55-year-old male found dead in his laundry with a pistol next to him. Police investigations could conclude a suicide. Native post-mortem CT (PMCT) (a, b) revealed a small cutaneous lesion with metallic particles in the skin corresponding to gunshot residues and indicating the entrance wound (arrow in a), a left haemothorax and a haemopericardium (b). PMCT-angiography (PMCTA) (c–e) could demonstrate an extravasation of contrast agent into the pericardium originating from a lesion of the myocardium in the left ventricle (arrow in c). Additionally, contrast agent indicated a trajectory through the pulmonary parenchyma (dotted arrow in c). The trajectory of the gun shot is reconstructed using the dynamic phase of multiphase PMCTA where the contrast agent indicates trajectories in soft tissue (d, e). In this case, the project described a descending trajectory directing from anterior to posterior and slightly from the left to the right considering an upright anatomical position.

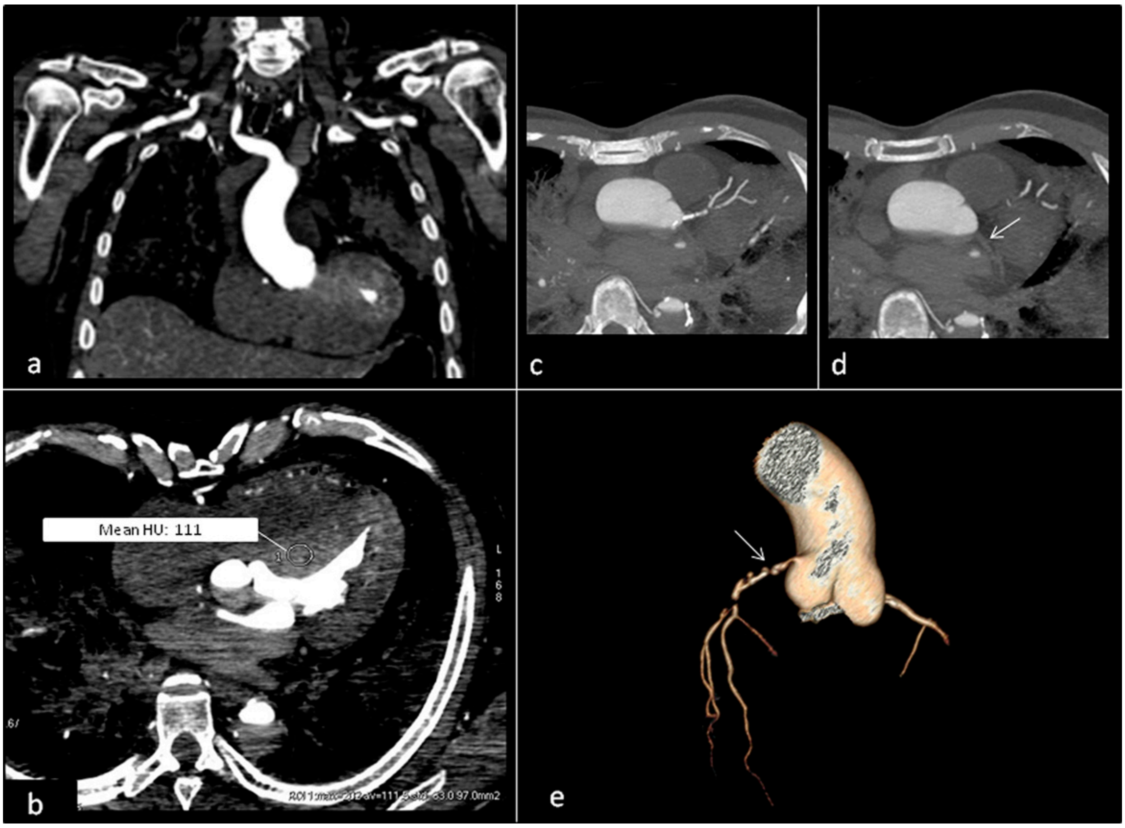


pressure to a certain degree and generate a small cardiac output,[49] thanks to chest compression. This fact is applied to the PMCTA technique, where the contrast media is injected into peripheral veins such as the cubital vein, as it is done in clinical, *in vivo*, contrast-enhanced CT investigations. The contrast agent enters the heart cavities from where it is dispersed into the pulmonary and body circulation, thanks to chest compression performed similarly to CPRs. These manoeuvres are carried out directly on the CT table for about 2 min and followed immediately by a CT-data acquisition. The images obtained visualize big parts of the arterial and venous system, depending on the investigated case. Lesions such as organ injuries and localization of the source of haemorrhage are stated to be visible thanks to the extravasation of the contrast media. Therefore, the most common indication of the examination seems to be traumatic death when CPRs in the emergency room did not lead to success.

THE FRENCH POST-MORTEM CT-ANGIOGRAPHY ALTERNATIVE

In 2011, Jolibert et al[50] published a technical note reporting an alternative method for PMA. The corpse of a young male was examined after a traffic accident. After catheterization of the femoral artery guided by ultrasound, the examining group used a pump that was regularly used for the application of contrast agents in clinical CT examinations to inject 400 ml of a mixture of iodinated contrast agent and water into the arterial system. The images obtained helped detect various major arterial lesions, which were consequently confirmed by autopsy. This case is interesting because of its close-to-clinical approach, namely the ultrasound-guided vascular access and the use of a regular clinical contrast agent and pump system. It must, however, be noted that this report is not suitable for demonstrating the strengths and weaknesses of the method, as it comprised only one case with a number of particularities, for example the short interval between death and examination (20 h), short interval between contrast agent injection and CT scan (scan started immediately after the injection), use of a newest generation CT scanner, relatively large arterial lesions, small amount of injected contrast agent (400 ml), no filling of the venous system etc. Complications encountered were an iliac artery dissection after puncture and a peripancreatic extravasation of contrast agent attributed to autolysis. Thus, the arterial access, the contrast agent and its

Figure 3. Multiphase post-mortem CT-angiography (MPMCTA) images of the arterial phase of a 63-year-old male found dead in his bed. Autopsy and histology revealed a subacute posteroseptal infarction of myocardium and a thrombosis of the circumflex artery. During the arterial phase of MPMCTA, a pathological enhancement of the myocardium can be observed (a, b), with a mean attenuation of 111 HU in the septum (b), indicating the region of the infarction. Maximum intensity projection (c, d) and 3D-volume rendering (e) reconstructions of the coronary arteries demonstrate multiple stenosis of the interventricular artery and the common trunk of the left coronary artery and a non-opacification of the circumflex artery (arrow in d and e). 3D, three-dimensional.



method of application need to be further evaluated before they can be profoundly judged.

Targeted coronary angiography techniques

The technique of today's TCA had been developed in England and originated from a requirement that medical cause should be given for all deaths in England and Wales.[51] As in cases of sudden unexpected death, the cause of death is not known; they are referred to Her Majesty's Coroner, who can request a PM investigation. Most of these cases are those of natural death, a considerable number of them dying because of cardiovascular diseases. Therefore, the investigation of cardiovascular death has become a major issue in the United Kingdom. This may be the reason why two English centres independent of each other decided to introduce PMCTA by injecting the contrast agent into the ascending aorta and thereby the coronary arteries.[52,53] Both techniques use the left carotid artery to introduce a urinary catheter, originally designated for bladder catheterization. The catheter balloon is then inflated in the ascending aorta, and the contrast agent is injected into the aortic root. Thanks to the aortic valve and the compliance of the ventricle muscle and mitral valve, the back flow into the heart is limited and the coronary arteries can be filled. Although both techniques are using standard clinical contrast agents dissolved in water, they have some differences. The method developed in Leicester consists in the injection of both air (negative contrast) and contrast media,[52] whereas the one developed in Oxford uses only positive contrast media and makes efforts to avoid getting air into the vessels.[53] Also, the injection techniques show variations. While the Oxford system uses a manual injection into the carotid artery, the research team in Leicester has introduced a standard clinical CT power-contrast injector. The coronary arteries are then imaged during the ongoing contrast injection. This aims, similar to the dynamic phase of MPMCTA, to mimic physiological pressure and provide a more meaningful assessment of vessel stenosis.[54,55] As positive contrast agents, both methods use clinical contrast agents dissolved in water, rendering them hypo-osmolar. Probably thanks to the small quantity of contrast agent used for TCA, there is no important tissue oedema observed that could affect further investigations such as histological analysis.[55] Both methods are declared to be fast and easy to perform as well as cost effective.[52,53]

First scientific studies investigating the performance of TCA have been already published, comparing the technique with autopsy[54,56] and histological investigations of coronary arteries.[54] They revealed that, similar to whole-body approaches, there are good correlations for identifying coronary lesions and therefore for investigating ischaemic heart disease. One study also discusses the fact that the minimally invasive approach of PMCTA may even have advantages over the conventional method of investigating coronary vessels as the invasive autopsy and histology approach represents a trauma for the vessels and can therefore lead to artefacts.

THE TECHNICAL WORKING GROUP POST-MORTEM ANGIOGRAPHY METHODS

PMCTA is an examination that aims to increase the sensitivity of PMCT. Although several studies conducted until today are proof that this aim can be achieved, until today most applied methods have remained at a research level, and the centres using PMCTA as a routine examination are rare. To become a technique that is accepted to the forensic scientific community and in jurisprudence, as a proof in court, standardized and validated methods are necessary. To optimize the workflow and allow the examination to be a part of the daily routine in a medicolegal centre, adequate material and formation of staff are necessary.

To satisfy all these needs to further develop and validate techniques of PMCTA, an international working group called the Technical Working Group Post-mortem Angiography Methods (TWGPAM) was created in February 2012.[57] Today, it consists of nine participating centres situated in six European countries: Switzerland (University of Lausanne and University of Basel), Germany (University of Hamburg, University of Munich and University of Leipzig), England (University of Leicester), Italy (University of Foggia), Poland (University of Krakow) and France (University of Toulouse). Each centre provides a team consisting in forensic pathologists, radiologists and radiographers. The teams or their leaders meet regularly for meetings, exchange data with each other and report cases on a secured homepage.

As a first research objective, the TWGPAM group has started a multicentre study to validate the technique of MPMCTA. In the context of this study, each centre should investigate about 50 cases using the standardized protocol of this method and standardized equipment (Virtangio® perfusion device and consumables, including the contrast agent Angiofil, provided one year free of charge by Fumedica AG). Similar to the study published by Chevallier et al,[40] data from native PMCT, MPMCTA and conventional autopsy shall be compared in 500 cases of medicolegal and clinical autopsy cases. The idea of this study is to definitely identify advantages and limitations of the method and to define indications for its application. Once this first multicentre study is completed, further studies are planned for the validation of other techniques and the development of new protocols for performing PMCTA.

Besides the performance of different studies, one big goal of the TWGPAM is the dispersion of knowledge. Therefore, the members of TWGPAM are organizing workshops at international meetings, and an MPMCTA workshop is held once a year. The next challenge for the team is the editing of an atlas for PMA, which should help physicians all over the world to start their own PMCTA examinations and give guidelines for the interpretation of radiological images.

SUMMARY

In the past years, PMCTA has been a field of intense research. Different approaches to investigate either the whole body (head–thorax–abdomen) or only the coronary arteries have been developed all over the world. Although the applied techniques differ concerning the injection method or the injection liquid, they all have one point in common: they are all stated to have great potential to increase the quality of the PM investigation because they reveal important information about the vascular system. This fact is not surprising, as it is well known in clinical CTA. The main interests for such PMCTA examinations are clearly cases of natural death owing to cardiovascular disease and trauma cases, and those investigated after medical interventions. In fact, the greatest strength of these techniques is to detect sources of haemorrhage and to investigate vascular stenosis or occlusions, although the latter still needs a confirmation, as for the moment, *in vivo* occlusions cannot be differentiated with certitude from occlusions due to PM changes.

To change the actual state of PMCTA from research to routine application, techniques need to be further investigated and standardized. Their artefacts, strength and pitfalls have to be known, and guidelines for the interpretation of the radiological data should be available. Only then can the techniques be used on delicate medicolegal cases and introduced into the workflow of a daily routine. First attempts to reach these goals have been made concerning the technique of MPMCTA, where several studies have been conducted to answer already a big part of the many open questions. Also, the techniques of TCA are being investigated in a structured and well-defined manner containing clear morphological comparison between a standardized technique and macro- and microscopic findings. The other techniques are still missing such basic studies and also the application of a standardized technique on a bigger case number.

To better introduce PMCT and PMCTA into the daily routine of legal medicine, some centres have already found a satisfying solution: the introduction of radiographers seem to be the answer for solving the problem of additional examination time and training for forensic pathologists.[58] In fact, the "forensic radiographer" has become a new subspecialty in some countries, and international training is today available.

Besides the validation of the existing techniques, there are also further things to develop: protocols for the investigation of superior and inferior members should be established, perfusion protocols for infants are needed and methods for selective angiography other than the coronary arteries would be of interest. All these missing points underline that the research of PMCTA is still at the beginning and a lot of work has to be done before its final role as a replacement or an adjunct to the conventional autopsy can be discussed. However, the development of PMCTA is surely one of the biggest steps in the direction of minimally invasive autopsy, thus pointing out the importance of active research in this field. The TWGPAM team was therefore created to push forward a systematic and target-oriented research.

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