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Review article

The impact of multiphase post-mortem CT- angiography (MPMCTA) for investigating fatal outcomes of medical interventions

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ABSTRACT

Post-mortem imaging - predominantly computed tomography (PMCT) - has proven its suitability in reported casework experience of suspected fatal medical errors to become an integral part of routine pre-autopsy forensic investigations. However, its role in mortality analysis within the context of hospital quality management is still under consideration. Post-mortem imaging combined with angiography procedures can effectively assist forensic autopsy investigations of unexpected and periprocedural deaths as they both offer a significant improvement in documenting medical complications. They help to identify misplaced medical devices, sources of haemorrhages, vascular patency, and unimpaired perfusion after general and cardiovascular surgery, complications after transvascular catheter-directed interventions or distinctive and potentially contributing features of vascular anatomy. Complications in transplant surgery demonstrate the significant impact of multiphase CT angiography (MPMCTA) as a standardised method of post-mortem opacification of the vasculature in the evaluation of bleeding complications following complex vascular surgery. Complicated transcatheter aortic valve implantations (TAVI) serve as examples for the application of MPMCTA in order to clarify fatal outcomes of catheter-guided minimal invasive interventions. Single casework experience favours that PMCT and PMCTA assist forensic or clinical autopsies to reconstruct adverse medical events with fatal outcomes or contribute substantially to prove a non- complicated interventional approach.

1. Introduction

Over the last 10 – 15 years, post-mortem computed tomography (PMCT) has developed into a tool for routine medico-legal work worldwide [1–7]. The first use of imaging as an instrument to verify medical errors dates back to 1895 [8], however, advantages of post-mortem imaging in cases with fatal outcomes after medical interventions have just recently started to be of broader interest [9], which is particularly encouraging since post-mortem angiography procedures are still developing [10–15]. PMCT- assisted autopsies of fatal complications have been reported for misplaced catheters, guidewires, tubes and drainages, sources of intervention-related haemorrhages and gas embolisms [9,11,16].

However, post-mortem imaging has not yet been established as an acknowledged tool for quality control in hospitals [13,16,17].

In casework with ambigious morphological findings at autopsy, typical cardiovascular causes of death can be confirmed by combining the autopsy with CT angiography and magnetic resonance imaging, predominantly sudden cardiac death [13,15,18,19].

Recently, PMCT angiography (PMCTA) has been reported to expand the range of options in the reconstruction of potential medical errors by facilitating the search for the source of a haemorrhage [14,16] or the documentation of unimpaired perfusion of the vasculature, which has been affected by surgery or endovascular intervention [14,15,18,20]. Key criteria for the decision to perform post-mortem imaging and for its interpretation can be obtained from the preliminary review of a deceased patient's medical history (unclear periprocedural complication in case of cardiovascular interventions, suspected haemorrhage of unclear origin, time course, manner and described success of emergency procedures/ surgical haemostasis [11,16]).

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The development of post-mortem angiographic procedures has substantially advanced over the past two decades [21,22,23]. The targeted coronary angiography fills the coronary arteries through cannulation of the aorta via the subclavian or neck arteries [24,25]. Apart from the selective assessment of localised vasculature, the multiphase post-mortem computed tomography angiography (MPMCTA) currently represents the technique for post-mortem whole-body perfusion [26], which has been evaluated in a relatively detailed manner [27]. In this minimally invasive procedure, the vascular system is perfused using a mixture of paraffin oil and Angiofil® infusion, an oily contrast agent designed for post-mortem examinations [28]. An analysis of a 200- out- of- 500-case series [27] validated a standardised method for perfusion by comparing it with autopsy results. Systematic analysis of the most important limitations of PMCTA methods have been reported on the differentiation of post-mortem clotting, the gastrointestinal tract [26] and the intracranial vasculature [29].

2. Methods

So far, the technical working group for post-mortem angiography methods (TWGPAM, founded in 2012, www.twgpam.org), has investigated approximately 300 hospital deaths from university medical centres using PMCTA - most of them in Hamburg-Eppendorf, Germany, where public prosecution has placed great emphasis into the clarification of suspected medical malpractices. Furthermore, PMCT(A) examinations are performed in Hamburg on request by clinical colleagues in cases of naturally certified deaths or if public prosecution denies further investigations, primarily in certified cases where the manner of death is unclear. Tab.1 demonstrates the range of medical procedures investigated after fatal outcome. The TWGPAM group has predominantly used 16-slice MDCT scanners since 2012. MPMCTA had been performed according to reported standard methods [30], but case-dependent variations have been established regarding the consecutive partition of standard amounts of contrast medium application during single phases into two or three parts and regarding the cannulation sites. In Hamburg, a whole body CT from top to thigh (slice thickness 1 mm, pitch 1.5, 130 kV, 180–230 mAs) is performed as a standard procedure, complemented by specific higher resolution scans of the cranium, the brain and the thorax (slice thickness 0.8 mm, pitch 1.0, 130 kV, 180–230 mAs). The final report is released by a combined team of board certified radiologists and forensic pathologists.

Table 1

Examples of fatal complications of medical interventions investigated by the TWGPAM group using MPMCTA.

- Vessel perforations after misplaced catheters (dialysis, miscellaneous)
- Vascular perforation during tracheotomy
- PTCA complications with or without hemopericardium
- Perforation/ haemorrhage after transcatheter aortic valve replacement = TAVR (transfemoral, transthoracic)
- Cardiac valvuloplasty –
  a. Mitral valve, triscuspid valve (annuloplasty, MitraClip®)
  b. Aortic valve: commissurotomy
- Vascular rupture after endovascular aortic repair EVAR
  a. combined with preceding hybrid vascular surgery
- Haemopericardium by a misplaced catheter in pulmonary vein ablation
- Fatal haemorrhage during heart and liver transplantation
- General abdominal surgery; removal of single or multiple organs, Whipple procedure
- Cardiothoracic surgery: Haemorrhage after pulmonary lobectomy or transthoracic aortic valve replacement
- ENT surgery: Haemorrhage following tonsillectomy
- Neurosurgery: Haemorrhage following occlusion of arteriovenous malformation

3. Results

The application of MPMCTA following fatal outcomes of medical procedures is described with exemplary cases, focussing first on complicated transvascular cardiac interventions and second on failed organ transplantations.

3.1. *Casework experience demonstrating fatal complications after transvascular interventions*

Coronary perforations with cardiac tamponade and dissections are typical fatal complications after transvascular cardiac interventions, such as percutaneous coronary interventions (PCI), sometimes resulting in aortic dissections. Perforations are caused by balloon expansions of the arterial wall or stent expansions, at times directly from a catheter tip in a vulnerable vessel wall [11]. In rare cases PMCTA fails to demonstrate the exact source of the bleeding which has caused the cardiac tamponade [16]. The tamponade is usually firmly clotted in these cases and prevents the contrast medium from leaking out of a rupture due to the massive pressure in the pericardial sac and blood clots adhering to the surface of the traumatised tissue.

A frequently observed intervention in recent years is the *transcatheter aortic valve implantation* (TAVI) that utilises bioprostheses made of bovine pericardium mostly mounted on an expandable stainless steel or cobalt-chromium stent [31]. The position of the valve, its relation to the coronary ostia with potential constriction effects including the unimpeded perfusion and integrity of the aortic outlet as well as signs of incompatible aortic diameter and the expanded stent frame with the risk of aortic insufficiency can be visualised by post-mortem angiography. The expanded mesh tube of the stent frame may complicate a subsequent coronary artery stent procedure. The lower border of the valve graft may interfere with the anterior sail of the mitral valve and its papillary suspension which can be observed using 3D reconstruction and virtual endoscopy [11,13]. However, being a catheter-guided vascular intervention, there is already a certain risk of damaging vascular walls in the initiation phase of the procedure when advancing the guide wires. Fig. 1 **(CASE 1)** exemplifies a fatal complication occurring during the aortic passage of the guide wire. It perforated the descending thoracic aorta, forming loops inside and outside of the vessel, resulting in a haematomediastinum and doublesided hematothorax. Nextofkin of the deceased expressed incomprehension to the fact that the medical doctors had provided different versions of the cause of the perforation stating on the one hand that the injury might have been caused while advancing the catheter and, on the other hand, while pulling out the catheter. A forensic autopsy confirmed the radiological findings. A second catheter had been inserted into the left groin successfully reaching the position for the TAVI placement at the aortic valve level but it had not been expanded until the time of death.

The TAVI procedure implies potential risks of vascular injury near the cannulation sites, particularly at the sheath insertion in the *transfemoral approach* if arterial sealing systems and sutures fail after terminating the intervention. Anticoagulation treatment promotes the development of life-threatening haemorrhages in the perivascular soft tissues of the thigh and retroperitoneum (**CASE 2,** Fig. 2). The *transapical approach* via a minimal thoracotomy and through the cardiac apex entails the risk of suture dehiscence causing a haematomediastinum and haematothorax [32]. MPMCTA demonstrates the situation at the time of death when surgical revisions sometimes manage to stop haemorrhages. This patient, however, died of a prolonged haemorrhagic shock.

Sometimes, positioning a TAVI prosthesis fails or perivalvular leak occurs, resulting in an implantation of a second prosthesis. In **CASE 3,** a valve-in-valve procedure (Fig. 3) followed after valve displacement had occurred during the retraction of the delivery catheter. MPMCTA demonstrates the integrity of the leftventricular outflow and patency of the coronary ostia. The patient died of myocardial infarction due to