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Post-mortem imaging in sudden death cases due to arterial or cardiac hemorrhage

Introduction

During the last decade post-mortem imaging has strengthened its position giving the opportunity for a revival of medico-legal autopsy examination. The milestones of this examination technique were set up by publications about Virtopsy® [1] as well as the second edition of Brogdon's forensic radiology [2]. Conventional autopsy replacement ideas seem to be restricted to compatibility between conventional and modern methods of examination heading to opportunities for higher level of objectivity [3]. Due to relatively good availability and moderate costs, the most popular technology applied in modern post-mortem imaging is post-mortem computed tomography (PMCT); however, unenhanced PMCT in violent and natural death cases may be insufficient similarly to conventional autopsy techniques in showing the actual source of bleeding related to the damage of blood vessels and even worse referring to evaluation of internal organ injuries. The addition of contrast agent (CA) administration provides the opportunity for successful supplementation of this examination technique into PMCT angiography (PMCTA).

Material and methods

In everyday practice of the authors' Department of Forensic Medicine, PMCT acquisitions are performed in almost every case directed to the department. With respect to the PMCTA, we implemented two main indications for this examina-

tion: victims of potential homicide especially due to sharp force trauma and cases screened by the PMCT with positive findings showing high possibility of internal bleeding. As a member of the Technical Working Group Postmortem

Angiography Methods (TWGPAM) [4] our Department took part in the multicenter study which included mostly violent death cases, referring to sharp force trauma and gunfire injuries; however, other cases with the potential interesting

Fig. 1 ▲ A 52-year-old female found in bushes under circumstances that suggested sexual assault; however, post-mortem examination excluded any violent cause of death: **a** thin coronal plane section of the head based on unenhanced PMCT showing signs of both subarachnoid and intraventricular hemorrhage; the arrow shows the location of the possible source of bleeding, **b** thick coronal plane of the head based on PMCTA in the dynamic phase showing CA extravasation at the base of the right side of the brain, **c** the autopsy specimen of the arteries at the base of the brain, showing the ruptured aneurysm (arrow) of the right middle cerebral artery ("inferior" view), **d** microscopic specimen, showing changes of the arterial wall and the aneurysm (H&E × 40)

Fig. 2 ▲ A 41-year-old male presenting with complaints of pain in the chest and the back, who had been examined two times (day by day) in hospital, finally discharged home where he died the next day. Post-mortem examination revealed the ruptured dissecting aortic aneurysm, spreading to carotid and iliac arteries, with two areas of rupture in the immediate vicinity of the base of the heart and the aortic arch: **a** thin axial plane of the thorax based on unenhanced PMCT showing blood inside the pericardial sac, **b** VRT reconstruction based on PMCTA at the arterial phase showing CA inside both lumens of the dissecting aortic aneurysm as well as CA extravasation into the pericardial sac, right posterior view, **c** the autopsy specimen showing internal wall of the aortic arch with the rupture and **d** microscopic specimen, showing dissection of the aortic wall with bleeding (H&E $\times 40$)

prospects for PMCTA evaluation were taken into consideration, including cases of natural deaths due to hemorrhage. In the current paper we present the results of both conventional and PMCT/PMCTA evaluation of five cases, including four ruptured aneurysms (one at the base of the brain, one of the abdominal aorta and two dissecting aneurysms of the thoracic aorta) and one cardiac rupture at the site of myocardial infarction. The cases included adults of both sexes, aged from 41 to 75 years old. The CT data acquisition was completed within 1–5 days after death. All cases were scanned using 16-layer tomography (Somatom Emotion, Siemens, Munich, Germany, kVp 130, mAs 50 and 240), reconstructed slice thickness 0.75 and 1.5, collimation 16×0.6 , and pitch 0.85 and 0.55. Before CA administration all cadavers were examined using unenhanced PMCT as well as external conventional examination and material sampling for toxicological examination

was performed. As a TWGPAM member, we applied whole-body examination utilizing the standardized CA protocol with the use of 6% oily liquid solution of Angiofil® (Fumedica, Muri, Switzerland), administered to femoral vessels. After imaging, a complete conventional internal autopsy examination was performed. Macroscopic examination was accompanied by histology with hematoxylin-eosin (H&E) staining of the heart, brain, lungs, liver, kidneys as well as the regions of hemorrhage (arterial and cardiac walls). The PMCT/PMCTA acquisition results were evaluated by two forensic pathologists with 9 years of experience in such examination and evaluation using the open source Digital Imaging and Communication (DICOM) viewer, OsiriX (Pixmeo SARL, Bernex, Switzerland, version 5.0.2), including the analysis of two-dimensional (2D) slices, multiplanar reformatted (MPR) images and formation of three-dimensional (3D) im-

ages by volume-rendered (VRT) reconstructions.

Results

The **Figs. 1, 2, 3, 4 und 5** show the results of both post-mortem imaging and conventional methods aimed at the source of bleeding/triggering cause of death.

Discussion

The PMCTA technique has only approximately 10 years of history of utilization for forensic pathology purposes [5]. An increasing number of forensic medicine institutes are using the PMCTA examination technique. Different methods of approach were presented, referring to targeted examination of selected regions of the deceased person [6, 7], with the attempts of validation of methods in comparison to microscopic [8] and conventional autopsy examinations [9]. Apart from different causes of vascular damage

in violent and natural death cases, there are other changes referring to blood vessel pathology taken into consideration, including diagnosis of pulmonary embolism [10], coronary thrombosis, and different aspects of coronary artery disease [11–13] including the possibility of myocardial changes visible after CA administration. Vascular changes at different locations [14] and due to specific illnesses [15] were reported. The use of PMCTA, at first aimed only at examination of bodies of deceased adults, has been introduced for other cases, even with problematic technical issues [16]. There are also reports referring to evaluation and visualization in cases after medical interventions related to the heart and great vessels [17, 18]. The publications are aimed not only at diagnostic efficiency but also present different methods of CA administration [10, 19, 20] with the propositions of standardized protocols [4, 21]. As we understand that there are no universal “remedies” for evaluation of all cases, the advances and limitations in the development of examination methods with the use of administration of CA to cadavers were discussed [22, 23]. A valuable achievement is that the presentation of cases referring to post-mortem imaging results are reaching scientific journals not only dedicated to forensic pathologists/radiologists, but also clinical disciplines [24], which may give the opportunity for better understanding of the value of post-mortem diagnosis for evaluation of clinical problems. Recent publications provide evidence that PMCTA may give forensic post-mortem examination additional strength [4]. Based on the cases presented in the current paper we may even claim that the PMCTA in selected cases might be the sufficient way of examination while combined with conventional external examination and toxicological sampling (investigation); however, histopathological examination of specimens (at least internal organs) seems to be necessary in cases of alleged medical error: for example, it may be crucial for the estimation of timing of critical changes (e.g. ruptures and necrosis).

At the present time there are no doubts that post-mortem imaging differs from

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Post-mortem imaging in sudden death cases due to arterial or cardiac hemorrhage

Abstract

The authors present cases of natural death due to arterial or cardiac hemorrhage evaluated using both conventional autopsy examination and post-mortem imaging, including post-mortem computed tomography angiography (PMCTA). Visualization based on CT scan acquisition are presented combined with the results of macroscopic and microscopic examination. Based on cases presented it can be seen that in selected cases PMCTA might be a sufficient method of examination while combined with conventional external examination and toxicological investigation; however, in

investigations of alleged medical malpractice cases, histopathological examination of specimens seems to be necessary. There are no doubts that post-mortem imaging differs from clinical examination. As we consider the history and the output of clinical imaging methods, there are plenty of challenges awaiting in the field of post-mortem imaging.

Keywords

Post-mortem examination · PMCTA · Aneurysm rupture · Cardiac rupture · Visualization

Postmortale Bildgebung bei plötzlichen Todesfällen aufgrund arterieller oder kardialer Blutungen

Zusammenfassung

Die Autoren präsentieren natürliche Todesfälle aufgrund arterieller oder kardialer Blutungen, die sowohl durch eine konventionelle Autopsie als auch mittels postmortaler Bildgebung, einschließlich postmortaler Computertomographie-Angiographie (PMCTA), beurteilt wurden. Die CT-basierte Visualisierung wird vorgestellt, in Kombination mit den Ergebnissen makroskopischer und mikroskopischer Untersuchungen. Anhand der vorgestellten Fälle wird deutlich, dass die PMCTA in selektierten Fällen als Untersuchungsverfahren ausreichend sein kann, wenn sie mit der konventionellen externen Untersuchung und der toxikologischen Erhebung kombiniert

wird; jedoch scheint bei der Untersuchung von Fällen, in denen angeblich ein ärztlicher Behandlungsfehler vorliegt, die histopathologische Untersuchung von Proben notwendig zu sein. Es besteht kein Zweifel, dass sich die postmortale Bildgebung von der klinischen Untersuchung unterscheidet. Betrachtet man die Entwicklung und die Ergebnisse der klinischen Bildgebungsverfahren, so wird es zahlreiche Herausforderungen im Bereich der postmortalen Bildgebung geben.

Schlüsselwörter

Postmortale Untersuchung · PMCTA · Aneurysmaruptur · Herzruptur · Visualisierung

Fig. 3 ▲ A 55-year-old woman with a history of hypertensive and Graves-Basedow diseases, under systematic medical supervision, collapsed and died unexpectedly. Post-mortem examination revealed widening of the circumference of the ascending aorta (up to 10 cm), the ruptured dissecting aortic aneurysm with two ruptures of the ascending aorta, both diameters approximately 1 cm: **a** thick axial plane of the thorax based on unenhanced PMCT showing blood inside the pericardial sac, **b** thin axial plane based on PMCTA at the arterial phase showing dissecting aortic aneurysm, **c** VRT reconstruction based on PMCTA at the arterial phase showing CA inside both lumens of the dissected aortic aneurysm as well as CA extravasation to the pericardial sac, left anterior view and **d** autopsy specimen showing dissecting aneurysm of the descending aorta

Fig. 4 ▲ A 75-year-old male suffered from pain in the inguinal area and subsequently lower back pain. He had been observed for several hours in hospital and discharged home, where he died on the same day: **a** thin axial plane of the abdomen based on unenhanced PMCT showing the changes located anteriorly to the spine and at the right side (suggesting bleeding because of ruptured aneurysm), **b** thin coronal plane based on PMCTA at the arterial phase showing ruptured aneurysm of abdominal aorta with CA extravasation to the right, note the cannulation of femoral vessels at the right side and **c** VRT reconstruction of the aneurysm based on PMCTA at the arterial phase, showing the leakage (arrow)

Fig. 5 ◀ A 56-year-old male without previous treatment died unexpectedly in the street. Forensic autopsy revealed areas of myocardial necrosis (pale red, partially yellowish tinted) of 9 × 3 cm in size, with the double rupture of the posterior wall (each about 1 cm) of the left ventricle at the apical region: **a** axial plane of the thorax based on unenhanced PMCT showing blood inside the pericardial sac, **b**, **c** both based on PMCTA at the arterial phase: thin axial (**b**) and coronal (**c**) plane showing CA leakage to the pericardial sac (*arrow*), **d** the autopsy specimen showing the apical part of the heart with the rupture (*encircled*), **e** the autopsy specimen with the cut in the left ventricle, showing the area of necrosis and rupture (*arrow*) and **f** microscopic specimen, showing different stages of necrosis of cardiomyocytes (H&E ×40)

clinical examination [25]. As we consider the history and the output of clinical imaging methods, there are plenty of challenges awaiting in the field of post-mortem imaging [26].

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Compliance with ethical guidelines

Conflict of interests. K. J. Woźniak, A. Moskała, E. Rzepecka-Woźniak, P. Kluza, K. Romaszko and O. Lopatin declare that they have no competing interests.

All studies described in this article were carried out in accordance with national law and the Helsinki Declaration from 1964 (in its current revised form). The PMCTA research was approved by the appropriate University Bioethics Committee (KBET/225/B/2012).

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References

1. Thali MJ, Dirnhofer R, Vock P (eds) (2009) The virtopsy approach: 3D optical and radiological scanning and reconstruction in forensic medicine. CRC Press, Boca Raton
2. Thali MJ, Viner M, Brogdon BG (eds) (2011) Brogdon's forensic radiology, 2nd edn. CRC Press, Boca Raton
3. Roberts IS, Benamore RE, Benbow EW, Lee SH, Harris JN, Jackson A, Mallett S, Patankar T, Peebles C, Roobottom C, Traill ZC (2012) Postmortem imaging as an alternative to autopsy in the diagnosis of adult deaths: a validation study. *Lancet* 379:136–142
4. Grabherr S, Grimm JM, Heinemann A (eds) (2016) Atlas of postmortem angiography. Springer, Heidelberg
5. Grabherr S, Djonov V, Yen K, Thali MJ, Dirnhofer R (2007) Postmortem angiography: review of former and current methods. *Am J Roentgenol* 188:832–838
6. Saunders S, Morgan B, Raj V, Robinson C, Rutty G (2011) Targeted postmortem computed tomography cardiac angiography: proof of concept. *Int J Legal Med* 125:609–616

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Nach Vorgaben des Krankenhausstrukturgesetzes soll die Auszahlung finanzieller Zuschläge für klinische Obduktionen im Krankenhaus an

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7. Roberts ISD, Benamore RE, Peebles C, Roobottom C, Traill ZC (2011) Diagnosis of coronary artery disease using minimally invasive autopsy: evaluation of a novel method of postmortem coronary CT angiography. *Clin Radiol* 66:645–650
8. Morgan B, Biggs MJ, Barber J, Raj V, Amoroso J, Hollingbury FE, Robinson C, Rutty GN (2013) Accuracy of targeted postmortem computed tomography coronary angiography compared to assessment of serial histological sections. *Int J Legal Med* 127:809–817
9. Inokuchi G, Yajima D, Hayakawa M, Motomura A, Chiba F, Torimitsu S, Makino Y, Iwase H (2013) The utility of postmortem computed tomography selective coronary angiography in parallel with autopsy. *Forensic Sci Med Pathol* 9:506–514
10. Pichereau C, Maury E, Monnier-Cholley L, Bourcier S, Lejour G, Alves M, Baudel JL, Ait Oufella H, Guidet B, Arrivé L (2015) Postmortem CT scan with contrast injection and chest compression to diagnose pulmonary embolism. *Intensive Care Med* 41:167–168
11. Michaud K, Grabherr S, Doenz F, Mangin P (2012) Evaluation of postmortem MDCT and MDCT-angiography for the investigation of sudden cardiac death related to atherosclerotic coronary artery disease. *Int J Cardiovasc Imaging* 28:1807–1822
12. Palmiere C, Lobrinus JA, Mangin P, Grabherr S (2013) Detection of coronary thrombosis after multi-phase postmortem CT-angiography. *Leg Med (Tokyo)* 15:12–18
13. Michaud K, Grabherr S, Jackowski C, Bollmann M, Doenz F, Mangin P (2014) Postmortem imaging of sudden cardiac death. *Int J Legal Med* 128:127–137
14. van Eijk RP, van der Zwan A, Bley RL, Regli L, Esposito G (2015) Novel application of postmortem CT angiography for evaluation of the intracranial vascular anatomy in cadaver heads. *AJR Am J Roentgenol* 205(6):1276–1280
15. Okura N, Okuda T, Shiotani S, Kohno M, Hayakawa H, Suzuki A, Kawasaki T (2013) Sudden death as a late sequel of Kawasaki disease: postmortem CT demonstration of coronary artery aneurysm. *Forensic Sci Int* 225:85–88
16. Sarda-Quarello L, Bartoli C, Laurent PE, Torrents J, Piercecchi-Marti MD, Sigaudy S, Arieu-Bonnet D, Gorincour G (2016) Whole body perinatal postmortem CT angiography. *Diagn Interv Imaging* 97(1):121–124
17. Vogel B, Heinemann A, Gehl A, Hasegawa I, Höpker WW, Poodendaen C, Tzikas A, Gulbins H, Reichenspurner H, Püschel K, Vogel H (2013) Post-mortem computed tomography (PMCT) and PMCT-angiography after transvascular cardiac interventions. *Arch Med Sadowej Kryminol* 63:255–266
18. Vogel B, Heinemann A, Tzikas A, Poodendaen C, Gulbins H, Reichenspurner H, Püschel K, Vogel H (2013) Post-mortem computed tomography (PMCT) and PMCT-angiography after cardiac surgery. Possibilities and limits. *Arch Med Sadowej Kryminol* 63:155–171
19. Robinson C, Barber J, Amoroso J, Morgan B, Rutty G (2013) Pump injector system applied to targeted postmortem coronary artery angiography. *Int J Legal Med* 127:661–666
20. Schweitzer W, Flach PM, Thali M, Laberke P, Gascho D (2016) Very economical immersion pump feasibility for postmortem CT angiography. *J Forensic Radiol Imaging* 5:8–14
21. Grabherr S, Doenz F, Steger B, Dirnhofer R, Dominguez A, Sollberger B, Gyax E, Rizzo E, Chevallier C, Meuli R, Mangin P (2011) Multi-phase postmortem CT angiography: development of a standardized protocol. *Int J Legal Med* 125:791–802
22. Grabherr S, Grimm J, Dominguez A, Vanhaebost J, Mangin P (2014) Advances in postmortem CT-angiography. *Br J Radiol* 87:20130488
23. 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* 34:830–846
24. Turillazzi E, Frati P, Pascale N, Pomara C, Grilli G, Viola RV, Fineschi V (2016) Multi-phase post-mortem CT-angiography: a pathologic correlation study on cardiovascular sudden death. *J Geriatr Cardiol* 13(10):855–865
25. Christe A, Flach P, Ross S, Spendlove D, Bolliger S, Vock P, Thali MJ (2010) Clinical radiology and postmortem imaging (Virtopsy) are not the same: specific and unspecific postmortem signs. *Leg Med (Tokyo)* 12:215–222
26. Aalders MC, Adolphi NL, Daly B, Davis GG, de Boer HH, Decker SJ, Dempers JJ, Ford J, Gerrard CY, Hatch GM, Hofman PAM, Iino M, Jacobsen C, Klein WM, Kubat B, Leth PM, Mazuchowski EL, Nolte KB, O'Donnell C, Thali MJ, van Rijn RR, Woźniak K (2017) Research in forensic radiology and imaging: Identifying the most important issues. *J Forensic Radiol Imaging* 8:1–8. <https://doi.org/10.1016/j.jofri.2017.01.004>