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FORENSIC RADIOLOGY SPECIAL FEATURE: REVIEW ARTICLE

Adult post-mortem imaging in traumatic and cardiorespiratory death and its relation to clinical radiological imaging

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ABSTRACT

The use of post-mortem imaging is expanding throughout the world with increasing use of advanced imaging techniques, such as contrast-enhanced CT and MRI. The questions asked of post-mortem imaging are complex and can be very different, for example for natural sudden death investigation will focus on the cause, whereas for trauma the cause of death is often clear, but injury patterns may be very revealing in investigating the background to the incident. Post-mortem imaging is different to clinical imaging regarding both the appearance of pathology and the information required, but there is much to learn from many years of clinical research in the use of these techniques. Furthermore, it is possible that post-mortem imaging research could be used not only for investigating the cause of death but also as a model to conduct clinically relevant research. This article reviews challenges to the development of post-mortem imaging for trauma, identification and cardiorespiratory death, and how they may be influenced by current clinical thinking and practice.

Generally, post-mortem investigation is carried out to ascertain four basic principles of who the deceased was, where they died, when they died and by what means (why) they came to their death. Imaging is normally only pertinent to the "whom" and "why" they died, and the emphasis on these questions may be completely different; for example a case of a witnessed natural death at home compared with a mass-fatality traumatic incident. A consistent theme, however, is that investigation should be carried out quickly and efficiently, for the sake of both the family and legal services.

Imaging in post-mortem investigation is as old as radiography (X-rays) itself, but there has recently been a massive expansion in the use of imaging techniques to assist or supplant traditional autopsy techniques in post-mortem investigation. Whilst there are few who doubt the ability of post-mortem CT (PMCT)[1] to demonstrate fractures, foreign bodies and major haemorrhagic injuries,[2] there have been many false dawns in this field. What is clear is that an "unenhanced" PMCT scan can only go so far in the investigation of death,[3–5] and the emphasis is now moving from non-invasive techniques to minimally invasive techniques, "enhancing" the scan.[6,7] Similar to development in the clinical world, many new imaging techniques struggle to live up to their hype.[8] However, by incremental progress, imaging has transformed clinical management in the living, and it is also likely to do so in the investigation of the cause of death.

This article looks into a few areas where research is ongoing to develop these techniques. The article concentrates on three main themes: the role of imaging in traumatic death, specifically relating to mass fatalities and disaster victim identification; the lessons that can be learnt from clinical imaging practice to inform the investigation of cardiovascular death; and, finally, the importance of other techniques being introduced, such as ventilation scans, dual source CT and MRI techniques.

TRAUMATIC DEATH AND IDENTIFICATION

Radiography is particularly useful in traumatic or suspicious deaths, and for many years this has proved satisfactory to aid identification (whom), particularly if accompanied by previous dental radiographs or dental records. Although DNA analysis and fingerprinting are preferred identification

strategies, forensic odontological/dental examination has many unique markers that may be compared with previous dental records or preferably radiographs. The other radiographic imaging is classified as a secondary identifying system but is recognized and may be necessary if dental assessment is not possible. These tests are particularly useful in a "closed" situation where the task is identification of bodies from a known list of victims (*e.g.* from a passenger manifest). This approach exploits the principle that many people have unique pre-existing injuries that may be visible to a plain radiograph, such as a fracture. This is particularly useful when radiographs can be compared with those taken in life, such as those used by Singleton[9] who managed to identify 24 of the 119 victims of SS Noronic fire disaster in 1949 by the sole use of radiology. However, with standard radiography, this can be a big task, such as for the Oklahoma City bombing response,[10] which used 60 radiographers and 10 radiologists over a 10-day period to do full skeletal surveys, giving 6 positive identifications where other techniques were inconclusive.

PMCT can offer all this from a single scan giving multiple potential identification options, including odontology,[11] medical implants, fractures and sinuses,[12] with new approaches still being identified. Although previous radiographs are more likely to be available than CT, PMCT images can be compared with previous radiographs using image manipulation.[13,14] PMCT has a further advantage over plain radiographs in the assessment of soft tissues. This can be useful for detecting visceral abnormalities, particularly those resulting from surgery such as cholecystectomy, which would not be detectable on standard radiography and could be used to identify a body.

Identification is much more difficult in an "open" disaster resulting in the death of unknown individuals or where there are no prior data or records available for comparison. In this situation, basic anthropological data are the starting point to establish the age and gender, and sometimes help in identifying the ethnicity of the victim. Standard anthropological examination often depends on osteology, which may require defleshing of bones, which is time consuming, destructive and against many religious and cultural beliefs.[15] PMCT three-dimensional (3D) reconstructions are particularly useful in the assessment of bone architecture and are reliable for anthropological assessments, and potentially answer most anthropological questions without the need to strip bones.[15–17] PMCT may also be useful in reuniting body parts in mass traumatic mortality.[18]

Radiography and fluoroscopy also help with the "by what means" question by locating fractures and foreign bodies, including bullets.[2] In many cases, the cause of death is all too obvious in trauma. However, patterns of injury may be important to reconstruct details of how the traumatic death came about or to locate evidence. CT is very good in this aspect, as shown for road traffic collisions.[19] PMCT has also proven to be useful in dealing with unlawful death, such as reconstructing bullet or stab wound trajectories.[20–23]

PMCT also has potential in the speed and efficiency of examination. Replacing traditional dental, fluoroscopic and standard X-ray equipment in a mass-fatality temporary mortuary could cut the examination time considerably and replace multiple radiation sources in a complex environment, improving radiation protection for staff.[24] PMCT, as a single mobile machine, can be moved anywhere and run on a generator, while the data can be handled and sent anywhere in the world.[25]

PMCT does have disadvantages compared with radiography. Intraoral metal dental work can cause artefacts. These artefacts can be ameliorated to some extent with modern equipment using an extended CT scale or with post-processing. However, a very dense material such as dental mercury amalgam can cause irrecoverable artefact owing to photon depletion. Rigor mortis, or deformity due to exposure to severe heat, can delay scanning if displaced limbs cannot easily fit through the CT aperture. Soft tissue release can be performed in cases of burning.[26]

It is likely that PMCT will become the primary advanced imaging modality for traumatic death in adults.[27] The PMCT and PM MRI (PMMR) balance is different in children for reasons relating to size and the types of relevant pathology suspected.[28] However, new roles are being discovered for MRI, for example MRI spectroscopy of the brain, which has been shown to correlate to time from death.[29] Other changes to the body that may occur after death, such as cooling, will also change the appearance of PMMR and need to be considered.[30] PMMR also has a role in investigation of trauma, not only because of its superior soft tissue contrast resolution but also to assess bone fractures. Clinical scanning with MRI can detect marrow oedema in the absence of a radiologically visible fracture,[31,32] and it is now being used in post-mortem investigation and can be useful to "date" fractures.[33,34] MRI is also particularly appealing for the forensic examination of strangulation in the living, owing to its good soft tissue contrast resolution and lack of radiation exposure.[35,36]

The biggest challenges to the scientific community to provide a rapid and efficient service are firstly logistical and financial. Running a CT scanner is expensive in terms of both capital outlay and staff costs. Furthermore, until PMCT is more widely available, bodies have to be transported to a PMCT centre as part of their investigation. For mass fatalities, a mobile CT scanner can be taken almost anywhere, but having such an expensive resource continually available requires considerable planning.

The second major task will be making sure that the evidence provided by imaging is believed. For example, plain film skeletal survey is a standard procedure for investigating sudden unexpected death in infancy,[37] but it is easy to propose that PMCT could replace this entirely and add extra information.[38] The principle of a radiographic skeletal survey to detect evidence of non-accidental injury predates the age of multidetector CT scanners.[39–41] However, there is a lack of evidence to show that PMCT can do this, showing that the ability of PMCT to detect trauma to the bone, in general, is not enough, as specific injuries such as the characteristic "bucket handle" metaphyseal fractures must be confidently excluded.[42] MRI may be sensitive to these metaphyseal fractures,[31,43] and it is therefore unlikely that CT would be used in living patients owing to radiation exposure.

This scenario demonstrates that all indications of PMCT in legal investigations should be clearly defined and should have their accuracy tested and validated by scientific review. Establishing the evidence for each indication and presenting it to the legal profession will become an important part of the ongoing research.[44,45]

CARDIOVASCULAR IMAGING

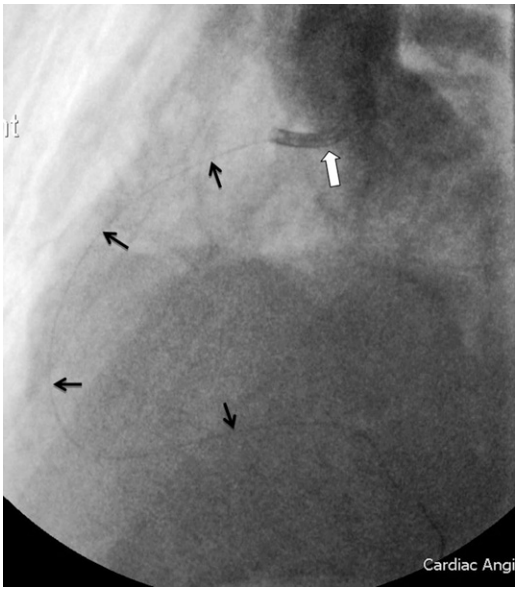
The subject of vascular imaging and specifically coronary vascular imaging is discussed elsewhere in this issue (Grabherr S, Grimm J, Dominguez A, Vanhaebost J, Mangin P. Advances in post-mortem CT angiography. Br J Radiol 2014;87:20130488). However, this is a key issue, being the most common cause of sudden death in adults, and has relevance even if the specific cause of death is non-cardiac, such as for a driver involved in a head-on road crash. Traditional autopsy and post-mortem imaging deliver a static view of tissue morphology, and previous studies have shown that luminal examination of the coronary arteries with PMCT angiography (PMCTA) can be equivalent to autopsy[46–49] but highlight that PMCTA does not provide intraplaque pathology, such as plaque rupture or haemorrhage[47] and cardiomyopathy.[50] However, plaque rupture when present is often associated with other critically stenosed lesions. Also, sudden death from coronary artery disease can be difficult to diagnose with absolute certainty during autopsy if death is caused by immediate causes such as arrhythmia, even in the presence of stenosis or thrombus.[51,52] Therefore, the cause of death is more commonly attributed to "ischaemic heart disease" on the "balance of probabilities", if no other cause of death is ascertained,[53,54] and pathologists often use an arbitrary 75% cut-off to define critical stenosis.[55] This is demonstrably a flawed approach because, although the cause of death as shown in Figure 3a (introduced later) is clearly a ruptured abdominal aortic aneurysm, the degree of coronary artery disease in this case is more severe than in many cases of documented ischaemic heart disease death.

One specific finding using targeted coronary PMCTA is that contrast injection under pressure can show luminal patency in regions of calcification where autopsy reports "critical stenosis".[47,56] The benefits of examining vessels under pressure during autopsy, and therefore mimicking normal physiological conditions, are well recognized but rarely performed in standard pathological practice.[57]

This raises a major question to post-mortem practice; how to interpret the significance of stenosis of the coronary arteries at post-mortem examination. The narrowing of a vessel appears to be a simple straightforward issue, but the full implications of stenosis are not yet fully understood. Even in clinical cardiac angiography, qualitative assessment of stenosis does not necessarily correlate with clinical significance,[58,59] although there is no doubt that severe coronary artery disease does predict for coronary occlusion.[60] It has been acknowledged that the functional significance of a vessel narrowing is more important than the actual narrowing; but as symptoms and clinical consequences vary between patients, gaining a full understanding of this is difficult. This is a key clinical question when assessing patients for suitability for a coronary artery stent. Current clinical investigations are now focused on the physiological impact of a stenosis.[61,62] Recently, direct measurement of pressure changes across a stenosis has become possible using a "pressure wire" to measure the pressure gradient across a stenosis [fractional flow reserve (FFR)]. It has been shown that FFR is more predictive of clinical benefit from coronary artery stent than luminal narrowing alone, and only 80% of the 70–90% diameter stenoses are functionally significant.[63] Treatment can therefore be targeted to functionally significant stenoses.[64] These techniques can be translated into post-mortem investigation, particularly if the coronary arteries are examined under controlled pressure.[56] It is possible to insert catheters into the coronary arteries in cadavers, including a "pressure wire" to measure intraluminal pressure and an optical coherence tomography (OCT) catheter to provide high-resolution "virtual histology" coronary images.[65] Intravascular ultrasound could also be used. Catheter insertion is difficult in a minimally invasive manner similar to clinical practice, as there is no circulation to guide catheters into the arterial orifices and the shapes of the unpressurised vessels are different, so more work is required to perfect this (Figure 1).

It is unlikely that these techniques will become routine, but they may contribute to a better understanding of coronary stenoses seen in post-mortem imaging. In clinical cardiology, FFR values may not directly correlate with maximal luminal narrowing, but they do correlate well with full 3D analysis of a stenosis.[66] Therefore, better mapping of stenoses in 3D may provide a better assessment of its likely impact. Performing this type of research in the post-mortem setting will improve our ability to assess the significance of lesions but may also provide a useful model to inform clinical practice.

Figure 1. An image from a fluoroscopic series showing a catheter inserted into the orifice of the right coronary artery (RCA) of a cadaver (white arrow) and a pressure wire inserted into the RCA (black arrows). Pressure changes in the RCA secondary to pump injection of air/contrast in the ascending aorta can then be measured.



Post-mortem imaging does not lend itself to the type of functional imaging used in clinical cardiac stress studies, but, if tissue perfusion can accurately be shown, then its deficit may indicate significant coronary artery stenosis[67] (Figure 2). However, this has yet to be shown in an autopsy controlled study and may provide too many false-positives to be a useful sign as, although perfusion loss in myocardial tissue may imply a significant stenosis, there is no way of knowing whether this is old or new, or caused by technical reasons such as air bubble or post-mortem clot (as opposed to pathological thrombus).

Dynamic imaging methods, including contrast studies, are becoming possible in the post-mortem setting using pressure injectors and contrast agents of differing molecular weights with different carrier molecules. However, it is rapidly becoming clear that the information obtained is not directly related to that from standard clinical studies and that the significance of tissue perfusion has to be assessed in the post-mortem setting and for all types of contrast agent. There is more flexibility in the use of contrast agents in PMCT as toxicity is not a concern, although some consideration has to be taken of the effect of any contrast medium on subsequent toxicology or DNA examination.[68–70] Generally, these can be lipophilic agents (dissolved in oil), barium particles in suspension or water-soluble iodinated chelates.[6] Agents, such as air or fat, that lower X-ray attenuation and appear black on traditional CT images may also be used as negative contrast agents (Figure 3).

All of these agents have their advantages and disadvantages. The key issues are related to their molecular size, viscosity, density and osmolality, which all dictate how they disperse in the body (pharmacokinetics). Currently, two broad approaches are used: the first is based on standard water-soluble agents in aqueous medium and the second uses water-soluble agents in a larger carrier solution, such polyethyleneglycol or lipophilic agents in oil. In clinical practice, water-soluble agents disperse rapidly from the intravascular space into the extravascular extracellular space (or interstitial space). This provides good tissue contrast, particularly where this vascular leak is rapid in one area compared with the adjacent tissues. This, however, requires rapid (dynamic) imaging after contrast agent delivery or there will be general dispersal in the tissues reducing this early "contrast". This is particularly important if purely vascular information is required. Contrast agents have been developed for clinical MRI scanning that leak more slowly into the extravascular extracellular space. Similar leakage into the interstitial space is noted in post-mortem contrast-enhanced imaging, although the pharmacokinetics are unlikely to be identical. Although this potentially allows imaging of tissue perfusion (Figure 2), it also presents two problems, particularly for whole body imaging: firstly, considerable dispersal will occur during the time required to pump the tracer around the body thereby reducing contrast in the image; and secondly, this leakage may cause alterations in osmolality in the interstitial space thereby causing oedema and histological changes that would affect subsequent autopsy results. This has been observed in whole-body studies but not localized targeted studies, presumably because of the lower amount of agent used.[48,49,71] To overcome this extravasation into the surrounding tissues, in whole-body studies polyethylene glycol has been added as a solvent[72,73] or, alternatively, a lipophilic iodinated contrast agent dissolved in paraffin oil. Using different solvents, the viscosity can be changed allowing the agent to enter capillaries and changing the information gained.[74]

However, to enable post-mortem contrast-enhanced imaging to follow clinical practice, it is important that more is understood about the dispersal patterns of these contrast agents and what this means in a pathophysiological sense. For example, contrast enhancement in normal tissues is common using water-soluble media but is exceptional using contrast in oily carriers where the contrast agent does not access the capillary bed as a result of the increase of viscosity (Figure 2b). However, exceptional soft tissue enhancement does occur in the brain, the renal cortex and the left ventricular myocardium, and may indicate dilatation of precapillary arterioles at the time of death.[72,73] It is possible that these contrast enhancement patterns will reveal information regarding physiology such as left ventricular hypertrophy, but

Figure 2. Cardiac images, in two different cases, of autopsy proven myocardial infarction, using (a) water-soluble contrast agent and (b) lipophilic contrast agent in paraffin oil. The water-soluble agent "enhanced" the normal myocardium showing perfusion deficits (*) relating to ischaemia, whereas the normal myocardium is not enhanced by the lipophilic agent, and at autopsy no oil was identifiable in the capillaries.

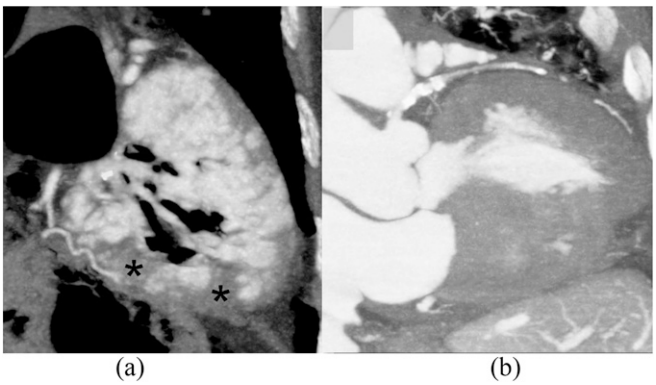


Figure 3. Whole-body angiography using (a) lipophilic contrast in paraffin oil (case of ruptured aortic aneurism) and (b) air (no vascular abnormality).

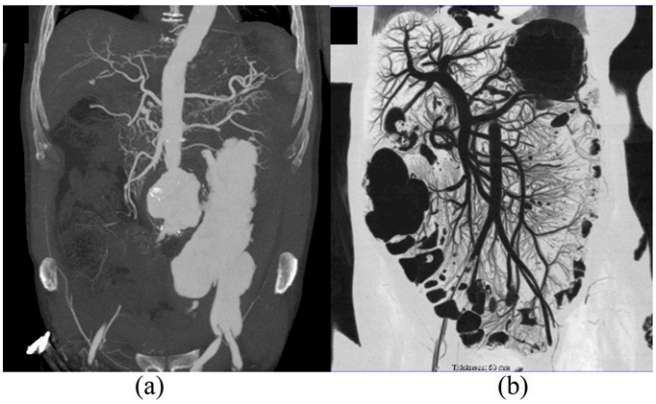
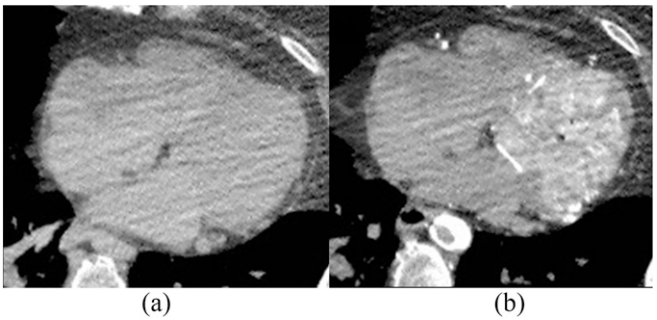


Figure 4. Images of the heart before (a) and after (b) lipophilic contrast in paraffin oil showing atypical myocardial enhancement in a case of death owing to hypertensive heart disease and obesity.



(a) (b)

this will require confirmation specific to the type of contrast agent and carrier it is injected with (Figure 4).

Another avenue that may indicate the significance of cardiac ischaemia is the use of MRI. Early work was not autopsy controlled,[75] while later articles were less optimistic,[4] but, more recently, changes on T_2 weighted images have been shown in animal models and clinical studies.[76–78] Clinical MRI scanning tells us that there may be more complex contrast enhancement changes that may be seen, such as the delayed myocardial enhancement occurring in regions of myocardial infarction.[79] Whole body contrast angiography is possible,[80] and there is no reason that targeted techniques cannot be translated to MRI, except for cost and time. Interestingly, information on coronary arteries has also been obtained without angiography, by using the absence of "chemical shift" artefact as a sign of a stenosed vessel.[81] Whether this turns out to be a helpful post-mortem or clinical sign[82] remains to be seen, but a clear message arising from this section is that post-mortem imaging has a lot to learn from advanced clinical imaging techniques. Furthermore, clinical imaging potentially has a lot to learn from post-mortem imaging, which may provide a good research model of human disease with which to test clinical paradigms.

RESPIRATORY IMAGING AND VENTILATION

Clinically, most chest CT scanning is performed during breath-hold after inspiration to clear atelectasis and "dependent" changes. This makes interstitial or nodular changes more apparent. Occasionally, both inspiration and expiration scans are performed to obtain functional information, such as for emphysema and air trapping.[83,84] Post-mortem scans may have obscuration of lung pathology owing to increase in pulmonary opacification (livor mortis), which can be mistaken for aspiration, pulmonary oedema or pneumonia.[85] These changes build up with greater delay from death to scan,[86] and the best interpretation of lung pathology has been shown within 2 h of death.[87,88] Pulmonary diagnosis is therefore perceived to be difficult in most cases.[38]

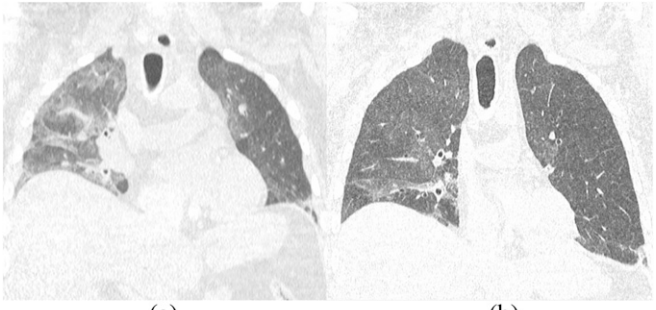
Being able to mimic ventilation in PMCT is therefore appealing to improve both the visibility of pathology and to provide functional information. Germerott et al[89–91] published a novel method called ventilation-PMCT using a portable homecare ventilator delivering intermittent pressures up to 40 mBar. Although these articles demonstrated the diagnostic advantages of applying such a technique, particularly in clearing background lung changes, they reported a number of potential problems ranging from the method of ventilation to movement artifact and gastric dilatation. We now routinely use this technique but have developed a technique for using supraglottic airways in all cases and use a ventilator set at 40 mBar constant pressure to avoid motion artefact.[92] The images are appealing as they clear background pulmonary changes without affecting significant pathology (Figure 5).

We anticipate that this approach may not only be useful in the diagnosis of traumatic and "natural" respiratory disease but also as a useful "dynamic" model to study diseased lung to aid clinical practice.

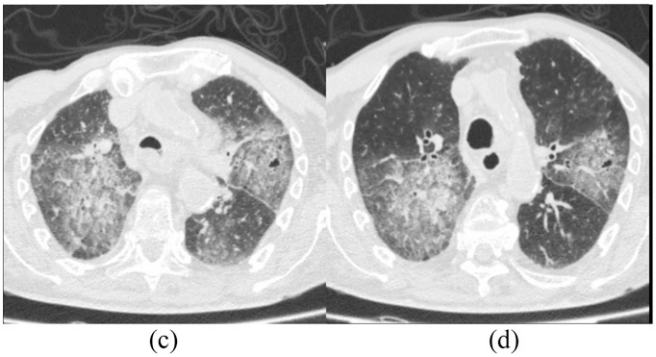
OTHER APPROACHES

There are many developments occurring in clinical imaging. Clearly, those related to targeted injectable tracers, such as nuclear medicine studies cannot be translated to the post-mortem setting. We have already discussed that, where translation is possible in the case of injected contrast agents, circulation pharmacokinetics may be different and require systematic re-evaluation for every new agent and setting. New cardiac imaging techniques such as OCT and intravascular ultrasound can be exploited. Two further new imaging modalities currently being tested in the post-mortem setting are dual source CT and developments in MRI scanning.

Figure 5. Post-mortem CT studies in two cases: normal (a, b) and with pneumonia (c, d) documented during autopsy. The second image of each case (b, d) is after lung ventilation using a supralaryngeal airway and continuous ventilation pressure of 40 mBar and shows clearing of normal background lung changes (b) but not pneumonia changes (d).



(a) (b)



(c) (d)

Dual source CT

Dual source CT was developed mainly to increase scan speed, but it does have the advantage of easily allowing "dual energy" CT. However, as the major obstacle to dual energy CT for single scanners is movement, dual energy PMCT can be performed on most "single source" modern scanners. The advantage of using dual energy is that if X-ray attenuation is known for two X-ray energies, the information gained is much more specific to the type of material. Dual energy CT can therefore separate materials of similar appearance, such as calcium and contrast agents, and identify foreign bodies. This makes contrast perfusion patterns more reliable and is being used clinically for both cardiac and lung perfusion studies. However, a key advantage for general indications is the better discrimination of soft tissues, a weakness of CT compared with MRI.[93–95] Whether dual source imaging becomes an essential component of post-mortem investigation is unclear, but it is likely to become an option on all clinical scanners and therefore for PMCT.

MR spectroscopy and diffusion weighted MRI

MRI allows morphological information to be obtained, in a similar fashion to CT. The great advantage of MRI, and possibly its curse in terms of cost and complexity, is the ability to image using multiple tissue contrast mechanisms. These contract mechanisms in the post-mortem setting are well reviewed elsewhere in this issue.[96] Two specific methods of MRI, MR spectroscopy (MRS) and "diffusion-weighted imaging" (DWI), provide potential information related to physiology and function in clinical practice. Although developed some time ago, their clinical utility is still increasing owing to advancing technology, and both techniques are now becoming available in all parts of the body and are simpler to use. MRS can give information related to molecular concentrations in a selected region, and this information can be registered with the anatomical images. Common metabolites that can be measured are lactate and choline, which link to ischaemia and cancer proliferation. More complex clinical MRI systems can test concentrations of metabolites related to other nuclei such as phosphorous. Considering these tools have been available to clinicians for many years, they are not widely used outside very narrow indications. However, MRS is becoming easier to perform and will become available to forensic investigators using clinical MR scanners. It remains to be seen whether these techniques will be useful and justify their cost and complexity.

Diffusion-weighted MRI is sensitive to microscopic water diffusion and therefore to tissue structure and cellularity. The technique can also use the asymmetry of diffusion caused by nerve sheaths (diffusion tensor imaging) to create maps of these nerve tracts (diffusion-weighted tractography). Clinically, DWI has multiple applications relating to ischaemia, cancer and discrimination of other pathologies, and its use is increasing because it is becoming easier to use in all parts of the body, not just the brain. There is evidence that these techniques can be used in the post-mortem setting, although the normal post-mortem appearance is radically different to the clinical normal, but may help with both time from death and cause, particularly in relation to the brain.[29,97–99]

CONCLUSIONS

What is clear from the multitude of research avenues is that the scientific community is still a long way from understanding the detailed post-mortem physiological changes that dictate tissue changes, contrast dispersal patterns and complex imaging findings. However, much has been learnt, and there is no doubt that imaging should be used in many different indications in the investigation of death. There is also no doubt that post-mortem imaging can be used to inform clinical practice, not just in the traditional manner of reviewing the medical care of an individual death, but as a model to investigate epidemiology, human disease processes and their treatment. Research will undoubtedly continue in testing the diagnostic ability of new techniques, and hopefully use these strategies to impact on clinical care. However, probably the most difficult type of research is to show that new techniques have an impact on public health.[100] This needs to be done by specifically validating techniques for all the indications they are required for.

REFERENCES

1. Rutty GN, Brogdon G, Dedouit F, Grabherr S, Hatch GM, Jackowski C, et al. Terminology used in publications for post-mortem cross-sectional imaging. *Int J Legal Med* 2013; **127**: 465–66. doi: 10.1007/s00414-012-0782-7
2. Donchin Y, Rivkind AI, Barziv J, Hiss J, Almog J, Drescher M. Utility of post-mortem computed-tomography in trauma victims. *J Trauma* 1994; **37**: 552–56.
3. Wichmann D, Obbelode F, Vogel H, Hoepker WW, Nierhaus A, Braune S, et al. Virtual autopsy as an alternative to traditional medical autopsy in the intensive care unit: a prospective cohort study. *Ann Intern Med* 2012; **156**: 123–30. doi: 10.7326/0003-4819-156-2-201201170-00008
4. Roberts IS, Benamore RE, Benbow EW, Lee SH, Harris JN, Jackson A, et al. Post-mortem imaging as an alternative to autopsy in the diagnosis of adult deaths: a validation study. *Lancet* 2012; **379**: 136–42. doi: 10.1016/S0140-6736(11)61483-9
5. Kasahara S, Makino Y, Hayakawa M, Yajima D, Ito H, Iwase H. Diagnosable and non-diagnosable causes of death by post-mortem computed tomography: a review of 339 forensic cases. *Leg Med* 2012; **14**: 239–45.
6. Grabherr S, Djonov V, Yen K, Thali MJ, Dirnhofer R. Postmortem angiography: review of former and current methods. *AJR Am J Roentgenol* 2007; **188**: 832–38. doi: 10.2214/AJR.06.0787
7. Saunders SL, Morgan B, Raj V, Rutty GN. Post-mortem computed tomography angiography: past, present and future. *Forensic Sci Med Pathol* 2011; **7**: 271–77. doi: 10.1007/s12024-010-9208-3
8. O'Donnell CJ, Woodford N. Imaging the dead. Can supplement but not replace autopsy in medicolegal death investigation. *BMJ* 2010; **341**: c7415.

9. Singleton AC. Roentgenological identification of victims of "Noronic" disaster. *Am J Roentgenol Radium Ther* 1951; **66**: 375–84.
10. Nye PJ, Tytle TL, Jarman RN, Eaton BG. The role of radiology in the Oklahoma City bombing. *Radiology* 1996; **200**: 541–43. doi: 10.1148/radiology.200.2.8685354
11. Thali MJ, Markwalder T, Jackowski C, Sonnenschein M, Dirnhofer R. Dental CT imaging as a screening tool for dental profiling: advantages and limitations. *J Forensic Sci* 2006; **51**: 113–19. doi: 10.1111/j.1556-4029.2005.00019.x
12. Ruder TD, Kraehenbuehl M, Gotsmy WF, Mathier S, Ebert LC, Thali MJ, et al. Radiologic identification of disaster victims: a simple and reliable method using CT of the paranasal sinuses. *Eur J Radiol* 2012; **81**: e132–38. doi: 10.1016/j.ejrad.2011.01.060
13. Riepert T, Ulmcke D, Schweden F, Nafe B. Identification of unknown dead bodies by X-ray image comparison of the skull using the X-ray simulation program FoXSIS. *Forensic Sci Int* 2001; **117**: 89–98.
14. Riepert T, Ulmcke D, Jendrysiak U, Rittner C. Computer-assisted simulation of conventional roentgenograms from three-dimensional computed tomography (CT) data–an aid in the identification of unknown corpses (FoXSIS). *Forensic Sci Int* 1995; **71**: 199–204.
15. Brough AL, Rutty GN, Black S, Morgan B. Post-mortem computed tomography and 3D imaging: anthropological applications for juvenile remains. *Forensic Sci Med Pathol* 2012; **8**: 270–79. doi: 10.1007/s12024-012-9344-z
16. Robinson C, Eisma R, Morgan B, Jeffery A, Graham EA, Black S, et al. Anthropological measurement of lower limb and foot bones using multi-detector computed tomography. *J Forensic Sci* 2008; **53**: 1289–95. doi: 10.1111/j.1556-4029.2008.00875.x
17. Sidler M, Jackowski C, Dirnhofer R, Vock P, Thali M. Use of multislice computed tomography in disaster victim identification–advantages and limitations. *Forensic Sci Int* 2007; **169**: 118–28. doi: 10.1016/j.forsciint.2006.08.004
18. Blau S, Robertson S, Johnstone M. Disaster victim identification: new applications for postmortem computed tomography. *J Forensic Sci* 2008; **53**: 956–61. doi: 10.1111/j.1556-4029.2008.00742.x
19. Leth PM, Struckmann H, Lauritsen J. Interobserver agreement of the injury diagnoses obtained by postmortem computed tomography of traffic fatality victims and a comparison with autopsy results. *Forensic Sci Int* 2013; **225**: 15–19. doi: 10.1016/j.forsciint.2012.03.028
20. Levy AD, Abbott RM, Mallak CT, Getz JM, Harcke HT, Champion HR, et al. Virtual autopsy: preliminary experience in high-velocity gunshot wound victims. *Radiology* 2006; **240**: 522–28. doi: 10.1148/radiol.2402050972
21. Buck U, Naether S, Braun M, Bolliger S, Friederich H, Jackowski C, et al. Application of 3D documentation and geometric reconstruction methods in traffic accident analysis: with high resolution surface scanning, radiological MSCT/MRI scanning and real data based animation. *Forensic Sci Int* 2007; **170**: 20–28.
22. Ruder TD, Ketterer T, Preiss U, Bolliger M, Ross S, Gotsmy WF, et al. Suicidal knife wound to the heart: challenges in reconstructing wound channels with post mortem CT and CT-angiography. *Leg Med (Tokyo)* 2011; **13**: 91–4. doi: 10.1016/j.legalmed.2010.11.005
23. Jeffery AJ, Rutty GN, Robinson C, Morgan B. Computed tomography of projectile injuries. *Clin Radiol* 2008; **63**: 1160–66. doi: 10.1016/j.crad.2008.03.003
24. Rutty GN, Robinson CE, BouHaidar R, Jeffery AJ, Morgan B. The role of mobile computed tomography in mass fatality incidents. *J Forensic Sci* 2007; **52**: 1343–49. doi: 10.1111/j.1556-4029.2007.00548.x
25. Rutty GN, Robinson C, Morgan B, Black S, Adams C, Webster P. Fimag: the United Kingdom disaster victim/forensic identification imaging system. *J Forensic Sci* 2009; **54**: 1438–42. doi: 10.1111/j.1556-4029.2009.01175.x
26. O'Donnell C, Iino M, Mansharan K, Leditscke J, Woodford N. Contribution of postmortem multidetector CT scanning to identification of the deceased in a mass disaster: experience gained from the 2009 Victorian bushfires. *Forensic Sci Int* 2011; **205**: 15–28. doi: 10.1016/j.forsciint.2010.05.026
27. Baglivo M, Winklhofer S, Hatch GM, Ampanozi G, Thali M, Ruder TD. The rise of forensic and post-mortem radiology—analysis of the literature between the years 2000 and 2011. *J Forensic Radiol Imaging* 2013; **1**: 3–9.
28. Thayyil S, Cleary JO, Sebire NJ, Scott RJ, Chong K, Gunny R, et al. Post-mortem examination of human fetuses: a comparison of whole-body high-field MRI at 9.4 T with conventional MRI and invasive autopsy. *Lancet* 2009; **374**: 467–75. doi: 10.1016/S0140-6736(09)60913-2
29. Ith M, Scheurer E, Kreis R, Thali M, Dirnhofer R, Boesch C. Estimation of the postmortem interval by means of ^{1}H MRS of decomposing brain tissue: influence of ambient temperature. *NMR Biomed* 2011; **24**: 791–98. doi: 10.1002/nbm.1623
30. Ruder TD, Hatch GM, Siegenthaler L, Ampanozi G, Mathier S, Thali MJ, et al. The influence of body temperature on image contrast in post mortem MRI. *Eur J Radiol* 2012; **81**: 1366–70. doi: 10.1016/j.ejrad.2011.02.062
31. Gufler H, Schulze CG, Wagner S, Baumbach L. MRI for occult physeal fracture detection in children and adolescents. *Acta Radiol* Feb 2013. Epub ahead of print. doi: 10.1177/0284185113475606
32. Tibrewal S, Jayakumar P, Vaidya S, Ang SC. Role of MRI in the diagnosis and management of patients with clinical scaphoid fracture. *Int Orthop* 2012; **36**: 107–10. doi: 10.1007/s00264-011-1350-3
33. Ruder TD, Germerott T, Thali MJ, Hatch GM. Differentiation of ante-mortem and post-mortem fractures with MRI: a case report. *Br J Radiol* 2011; **84**: e75–78. doi: 10.1259/bjr/10214495
34. Ross S, Ebner L, Flach P, Brodhage R, Bolliger SA, Christe A, et al. Postmortem whole-body MRI in traumatic causes of death. *AJR Am J Roentgenol* 2012; **199**: 1186–92. doi: 10.2214/AJR.12.8767
35. Yen K, Vock P, Christe A, Scheurer E, Plattner T, Schoen C, et al. Clinical forensic radiology in strangulation victims: forensic expertise based on magnetic resonance imaging (MRI) findings. *Int J Legal Med* 2007; **121**: 115–23. doi: 10.1007/s00414-006-0121-y
36. Christe A, Oesterhelweg L, Ross S, Spendlove D, Bolliger S, Vock P, et al. Can MRI of the neck compete with clinical findings in assessing danger to life for survivors of manual strangulation? A statistical analysis. *Leg Med (Tokyo)* 2010; **12**: 228–32. doi: 10.1016/j.legalmed.2010.05.004
37. Kennedy H. Sudden unexpected death in infancy. A multi-agency protocol for care and investigation. The report of a working group convened by the Royal College of Pathologists and the Royal College of Paediatrics and Child Health. London, UK: RCPath/RCPCH; 2004.
38. Proisy M, Marchand AJ, Loget P, Bouvet R, Roussey M, Pele F, et al. Whole-body post-mortem computed tomography compared with autopsy in the investigation of unexpected death in infants and children. *Eur Radiol* 2013; **23**: 1711–19. doi: 10.1007/s00330-012-2738-1
39. Dwek JR. The radiographic approach to child abuse. *Clin Orthop Relat Res* 2011; **469**: 776–89. doi: 10.1007/s11999-010-1414-5

40. Saulsbury FT, Alford BA. Intracranial bleeding from child abuse: the value of skull radiographs. *Pediatr Radiol* 1982; **12**: 175–78.
41. Kleinman PK, Marks SC Jr, Richmond JM, Blackbourne BD. Inflicted skeletal injury: a postmortem radiologic-histopathologic study in 31 infants. *AJR Am J Roentgenol* 1995; **165**: 647–50. doi: 10.2214/ajr.165.3.7645487
42. Lonergan GJ, Baker AM, Morey MK, Boos SC. From the archives of the AFIP. Child abuse: radiologic-pathologic correlation. *Radiographics* 2003; **23**: 811–45. doi: 10.1148/rg.234035030
43. Perez-Rossello JM, Connolly SA, Newton AW, Zou KH, Kleinman PK. Whole-body MRI in suspected infant abuse. *AJR Am J Roentgenol* 2010; **195**: 744–50. doi: 10.2214/AJR.09.3364
44. Ampanozi G, Zimmermann D, Hatch GM, Ruder TD, Ross S, Flach PM, et al. Format preferences of district attorneys for post-mortem medical imaging reports: understandability, cost effectiveness, and suitability for the courtroom: a questionnaire based study. *Leg Med (Tokyo)* 2012; **14**: 116–20. doi: 10.1016/j.legalmed.2011.12.008
45. 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* 2011; **64**: 711–17. doi: 10.1136/jclinpath-2011-200008
46. Michaud K, Grabherr S, Doenz F, Mangin P. Evaluation of postmortem MDCT and MDCT-angiography for the investigation of sudden cardiac death related to atherosclerotic coronary artery disease. *Int J Cardiovasc Imaging* 2012; **28**: 1807–22. doi: 10.1007/s10554-012-0012-x
47. Morgan B, Biggs MJ, Barber J, Raj V, Amoroso J, Hollingbury FE, et al. Accuracy of targeted post-mortem computed tomography coronary angiography compared to assessment of serial histological sections. *Int J Legal Med* 2013; **127**: 809–17. doi: 10.1007/s00414-012-0790-7
48. Roberts IS, Benamore RE, Peebles C, Roobottom C, Traill ZC. Diagnosis of coronary artery disease using minimally invasive autopsy: evaluation of a novel method of post-mortem coronary CT angiography. *Clin Radiol* 2011; **66**: 645–50. doi: 10.1016/j.crad.2011.01.007
49. Saunders SL, Morgan B, Raj V, Robinson CE, Rutty GN. Targeted post-mortem computed tomography cardiac angiography: proof of concept. *Int J Legal Med* 2011; **125**: 609–16. doi: 10.1007/s00414-011-0559-4
50. Michaud K, Grabherr S, Jackowski C, Bollmann MD, Doenz F, Mangin P. Postmortem imaging of sudden cardiac death. *Int J Legal Med* Jan 2013. Epub ahead of print. doi: 10.1007/s00414-013-0819-6
51. Arbustini E, Grasso M, Diegoli M, Morbini P, Aguzzi A, Fasani R, et al. Coronary thrombosis in non-cardiac death. *Coron Artery Dis* 1993; **4**: 751–59.
52. Adlam D, Antoniades C, Lee R, Diesch J, Shirodaria C, Taggart D, et al. OCT characteristics of saphenous vein graft atherosclerosis. *JACC Cardiovasc Imaging* 2011; **4**: 807–09. doi: 10.1016/j.jcmg.2011.01.021
53. Dorries C. Coroners courts: a guide to law and practice. 2nd edn. Oxford, UK: Oxford University Press; 2004.
54. Dorries C. The verdict: standard of proof. In: *Coroners courts: a guide to law and practice.* 2nd edn. Oxford, UK: Oxford University Press; 2004. p. 260.
55. Champ CS, Coghill SB. Visual aid for quick assessment of coronary artery stenosis at necropsy. *J Clin Pathol* 1989; **42**: 887–88.
56. Robinson C, Barber J, Amoroso J, Morgan B, Rutty G. Pump injector system applied to targeted post-mortem coronary artery angiography. *Int J Legal Med* 2013; **127**: 661–66. doi: 10.1007/s00414-012-0802-7
57. Coghill SB, Nicoll SM, McKimmie A, Houston I, Matthew BM. Revitalising postmortem coronary angiography. *J Clin Pathol* 1983; **36**: 1406–09.
58. Topol EJ, Nissen SE. Our preoccupation with coronary luminology. The dissociation between clinical and angiographic findings in ischemic heart disease. *Circulation* 1995; **92**: 2333–42.
59. Little WC, Constantinescu M, Applegate RJ, Kutcher MA, Burrows MT, Kahl FR, et al. Can coronary angiography predict the site of a subsequent myocardial infarction in patients with mild-to-moderate coronary artery disease? *Circulation* 1988; **78**: 1157–66.
60. Moise A, Lesperance J, Theroux P, Taeymans Y, Goulet C, Bourassa MG. Clinical and angiographic predictors of new total coronary occlusion in coronary artery disease: analysis of 313 nonoperated patients. *Am J Cardiol* 1984; **54**: 1176–81.
61. Bech GJ, De BB, Pijls NH, de Muinck ED, Hoorntje JC, Escaned J, et al. Fractional flow reserve to determine the appropriateness of angioplasty in moderate coronary stenosis: a randomized trial. *Circulation* 2001; **103**: 2928–34.
62. Pijls NH. Fractional flow reserve after previous myocardial infarction. *Eur Heart J* 2007; **28**: 2301–02. doi: 10.1093/eurheartj/ehm333
63. Tonino PA, Fearon WF, De BB, Oldroyd KG, Leesar MA, Ver Lee PN, et al. Angiographic versus functional severity of coronary artery stenoses in the FAME study fractional flow reserve versus angiography in multivessel evaluation. *J Am Coll Cardiol* 2010; **55**: 2816–21.
64. Pijls NH, van SP, Manoharan G, Boersma E, Bech JW, Van't VM, et al. Percutaneous coronary intervention of functionally nonsignificant stenosis: 5-year follow-up of the DEFER Study. *J Am Coll Cardiol* 2007; **49**: 2105–11. doi: 10.1016/j.jacc.2007.01.087
65. Adlam D, Joseph S, Robinson C, Rousseau C, Barber J, Biggs M, et al. Coronary optical coherence tomography: minimally invasive virtual histology as part of targeted post-mortem computed tomography angiography. *Int J Legal Med* 2013; **127**: 991–96. doi: 10.1007/s00414-013-0837-4
66. Morris PD, Ryan D, Morton AC, Lycett R, Lawford PV, Hose DR, et al. Virtual fractional flow reserve from coronary angiography: modeling the significance of coronary lesions: results from the VIRTU-1 (VIRTUal Fractional Flow Reserve From Coronary Angiography) study. *JACC Cardiovasc Interv* 2013; **6**: 149–57. doi: 10.1016/j.jcin.2012.08.024
67. Roberts IS, Traill Z. Minimally invasive autopsy employing postmortem CT and targeted coronary angiography: evaluation of its application to a routine Coronial service. *Histopathology* 2014; **64**: 211–17. doi: 10.1111/his.12271
68. Rutty GN, Smith P, Visser T, Barber J, Amorosa J, Morgan B. The effect on toxicology, biochemistry and immunology investigations by the use of targeted post-mortem computed tomography angiography. *Forensic Sci Int* 2013; **225**: 42–7. doi: 10.1016/j.forsciint.2012.05.012
69. Rutty GN, Barber J, Amoroso J, Morgan B, Graham EA. The effect on cadaver blood DNA identification by the use of targeted and whole body post-mortem computed tomography angiography. *Forensic Sci Med Pathol* 2013; **9**: 489–95. doi: 10.1007/s12024-013-9467-x
70. Grabherr S, Widmer C, Iglesias K, Sporkert F, Augsburger M, Mangin P, et al. Post-mortem biochemistry performed on vitreous humor after postmortem CT-angiography. *Leg Med (Tokyo)* 2012; **14**: 297–303. doi: 10.1016/j.legalmed.2012.04.010

71. Jackowski C, Sonnenschein M, Thali MJ, Aghayev E, von AG, Yen K, et al. Virtopsy: postmortem minimally invasive angiography using cross section techniques–implementation and preliminary results. *J Forensic Sci* 2005; **50**: 1175–86.
72. Jackowski C, Bolliger S, Aghayev E, Christe A, Kilchoer T, Aebi B, et al. Reduction of postmortem angiography-induced tissue edema by using polyethylene glycol as a contrast agent dissolver. *J Forensic Sci* 2006; **51**: 1134–37. doi: 10.1111/j.1556-4029.2006.00207.x
73. Jackowski C, Persson A, Thali MJ. Whole body postmortem angiography with a high viscosity contrast agent solution using poly ethylene glycol as contrast agent dissolver. *J Forensic Sci* 2008; **53**: 465–68. doi: 10.1111/j.1556-4029.2008.00673.x
74. Grabherr S, Hess A, Karolczak M, Thali MJ, Friess SD, Kalender WA, et al. Angiofil-mediated visualization of the vascular system by microcomputed tomography: a feasibility study. *Microsc Res Tech* 2008; **71**: 551–56. doi: 10.1002/jemt.20585
75. Bisset R. Magnetic resonance imaging may be alternative to necropsy. *BMJ* 1998; **317**: 1450.
76. Jackowski C, Schwendener N, Grabherr S, Persson A. Post-mortem cardiac 3-T magnetic resonance imaging: visualization of sudden cardiac death? *J Am Coll Cardiol* 2013; **62**: 617–29. doi: 10.1016/j.jacc.2013.01.089
77. Ruder TD, Ebert LC, Khattab AA, Rieben R, Thali MJ, Kamat P. Edema is a sign of early acute myocardial infarction on post-mortem magnetic resonance imaging. *Forensic Sci Med Pathol* 2013; **9**: 501–05. doi: 10.1007/s12024-013-9459-x
78. Shiotani S, Yamazaki K, Kikuchi K, Nagata C, Morimoto T, Noguchi Y, et al. Post-mortem magnetic resonance imaging (PMMRI) demonstration of reversible injury phase myocardium in a case of sudden death from acute coronary plaque change. *Radiat Med* 2005; **23**: 563–65.
79. Vogel-Claussen J, Rochitte CE, Wu KC, Kamel IR, Foo TK, Lima JAC, et al. Delayed enhancement MR imaging: utility in myocardial assessment. *Radiographics* 2006; **26**: 795–810. doi: 10.1148/rg.263055047
80. Ruder TD, Hatch GM, Ebert LC, Flach PM, Ross S, Ampanozi G, et al. Whole body postmortem magnetic resonance angiography. *J Forensic Sci* 2012; **57**: 778–82. doi: 10.1111/j.1556-4029.2011.02037.x
81. Ruder TD, Bauer-Kreutz R, Ampanozi G, Rosskopf AB, Pilgrim TM, Weber OM, et al. Assessment of coronary artery disease by post-mortem cardiac MR. *Eur J Radiol* 2012; **81**: 2208–14. doi: 10.1016/j.ejrad.2011.06.042
82. Shriki JE, Surti KS, Farvid AF, Lee CC, Samadi S, Hirschbeinv J, et al. Chemical shift artifact on steady-state free precession cardiac magnetic resonance sequences as a result of lipomatous metaplasia: a novel finding in chronic myocardial infarctions. *Can J Cardiol* 2011; **27**: 664–23.
83. Zaporozhan J, Ley S, Eberhardt R, Weinheimer O, Iliyushenko S, Herth F, et al. Paired inspiratory/expiratory volumetric thin-slice CT scan for emphysema analysis: comparison of different quantitative evaluations and pulmonary function test. *Chest* 2005; **128**: 3212–20. doi: 10.1378/chest.128.5.3212
84. Prosch H, Schaefer-Prokop CM, Eisenhuber E, Kienzl D, Herold CJ. CT protocols in interstitial lung diseases—a survey among members of the European Society of Thoracic Imaging and a review of the literature. *Eur Radiol* 2013; **23**: 1553–63. doi: 10.1007/s00330-012-2733-6
85. Christe A, Flach P, Ross S, Spendlove D, Bolliger S, Vock P, et al. Clinical radiology and postmortem imaging (virtopsy) are not the same: specific and unspecific postmortem signs. *Leg Med (Tokyo)* 2010; **12**: 215–22. doi: 10.1016/j.legalmed.2010.05.005
86. Shiotani S, Kobayashi T, Hayakawa H, Kikuchi K, Kohno M. Postmortem pulmonary edema: a comparison between immediate and delayed postmortem computed tomography. *Leg Med (Tokyo)* 2011; **13**: 151–55. doi: 10.1016/j.legalmed.2010.12.008
87. Shiotani S, Kohno M, Ohashi N, Yamazaki K, Nakayama H, Watanabe K, et al. Non-traumatic postmortem computed tomographic (PMCT) findings of the lung. *Forensic Sci Int* 2004; **139**: 39–48.
88. Michiue T, Sakurai T, Ishikawa T, Oritani S, Maeda H. Quantitative analysis of pulmonary pathophysiology using postmortem computed tomography with regard to the cause of death. *Forensic Sci Int* 2012; **220**: 232–38. doi: 10.1016/j.forsciint.2012.03.007
89. Germerott T, Preiss US, Ebert LC, Ruder TD, Ross S, Flach PM, et al. A new approach in virtopsy: postmortem ventilation in multislice computed tomography. *Leg Med (Tokyo)* 2010; **12**: 276–79. doi: 10.1016/j.legalmed.2010.07.001
90. Germerott T, Flach PM, Preiss US, Ross SG, Thali MJ. Postmortem ventilation: a new method for improved detection of pulmonary pathologies in forensic imaging. *Leg Med (Tokyo)* 2012; **14**: 223–28. doi: 10.1016/j.legalmed.2012.03.003
91. Germerott T, Preiss US, Ross SG, Thali MJ, Flach PM. Postmortem ventilation in cases of penetrating gunshot and stab wounds to the chest. *Leg Med (Tokyo)* 2013; **15**: 298–302. doi: 10.1016/j.legalmed.2013.08.002
92. Robinson C, Biggs MJ, Amoroso J, Pakkal M, Morgan B, Rutty GN. Post-mortem computed tomography ventilation; simulating breath holding. *Int J Legal Med* Nov 2013. Epub ahead of print. doi: 10.1007/s00414-013-0943-3
93. Persson A, Jackowski C, Engstrom E, Zachrisson H. Advances of dual source, dual-energy imaging in postmortem CT. *Eur J Radiol* 2008; **68**: 446–55. doi: 10.1016/j.ejrad.2008.05.008
94. Johnson TR, Krauss B, Sedlmair M, Grasruck M, Bruder H, Morhard D, et al. Material differentiation by dual energy CT: initial experience. *Eur Radiol* 2007; **17**: 1510–17. doi: 10.1007/s00330-006-0517-6
95. Ruder TD, Thali Y, Bolliger SA, Somaini-Mathier S, Thali MJ, Hatch GM, et al. Material differentiation in forensic radiology with single-source dual-energy computed tomography. *Forensic Sci Med Pathol* 2013; **9**: 163–69. doi: 10.1007/s12024-012-9398-y
96. Ruder TD, Thali MJ, Hatch GM. Essentials of forensic post-mortem MR imaging in adults. *Br J Radiol* Nov 2013. Epub ahead of print.
97. Schmidt TM, Fischer R, Acar S, Lorenzen M, Heinemann A, Wedegartner U, et al. DWI of the brain: postmortal DWI of the brain in comparison with in vivo data. *Forensic Sci Int* 2012; **220**: 180–83. doi: 10.1016/j.forsciint.2012.02.022
98. Scheurer E, Lovblad KO, Kreis R, Maier SE, Boesch C, Dirnhofer R, et al. Forensic application of postmortem diffusion-weighted and diffusion tensor MR imaging of the human brain in situ. *AJNR Am J Neuroradiol* 2011; **32**: 1518–24. doi: 10.3174/ajnr.A2508
99. Kobayashi T, Shiotani S, Kaga K, Saito H, Saotome K, Miyamoto K, et al. Characteristic signal intensity changes on postmortem magnetic resonance imaging of the brain. *Jpn J Radiol* 2010; **28**: 8–14. doi: 10.1007/s11604-009-0373-9
100. Mackenzie R, Dixon AK. Measuring the effects of imaging: an evaluative framework. *Clin Radiol* 1995; **50**: 513–18.