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Postmortem Imaging: An Update

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Postmortem imaging is a fascinating field of forensic radiology that has seen extraordinary growth in the last 10 years. Indeed, if autopsy represents the sole reliable method of determining the definitive cause of death, imaging may provide an efficient guide to supplement conventional autopsy. This is particularly true because of several techniques that are currently available, such as postmortem computed tomography, multiphase postmortem computed tomography angiography, and postmortem magnetic resonance imaging. In this review, we explore the newer imaging techniques in forensic radiology.

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Introduction

Since forensic science has been recognized as a branch of medicine that deals with relationships and applications of medical knowledge to legal problems, forensic radiology represents a further extension of forensics that, by means of all imaging techniques available, has the purpose to provide evidence, to support a diagnosis, to help interpretation of the facts, to guide the autopsy and, sometimes to perform a virtual autopsy (virtopsy).¹

Forensic radiology was actually born during the very early days of radiology in a case of an attempted murder that occurred in Montreal in 1895. The real cornerstone in forensic radiology occurred 70 years later with the introduction of CT when Wullenweber et al used CT in a case of a gunshot injury.^{2,3} Since that moment the use of CT revolutionized forensic imaging, providing

extraordinary anatomical details and precise localization of foreign bodies, such as bullets or fragments in the cadaver. Later, Dirnhofer and Vock introduced the “Virtopsy project” with the inclusion of 3-dimensional (3D) reconstruction and surface scanning, to identify and document different patterns of injuries.⁴⁻⁶ Thanks to a multi-disciplinary approach, this project tried to provide a standardized method usable in forensic fields, so that Thali et al suggested the expression of “Virtual Autopsy” in 2002.^{7,8}

In the era of evidence-based medicine, the scientific methodology must be applied to forensics to ensure validity for the Court. Accordingly, in the hopes of guaranteeing the best forensic practice, radiology is particularly appealing because imaging can produce evidence of high diagnostic credibility and documentary power.

To accomplish this end, all radio-diagnostic imaging techniques must be involved, each one taking advantage of its own particular strength determined by the physical principle used. The list includes conventional X-rays, computed tomography (CT) using ionizing radiation, magnetic resonance imaging (MRI) using intense magnetic fields and radiofrequency, and, the less used, ultrasound. The latter modality is inopportune in cadavers because of the obscuring gases from putrefaction. Its applicability, therefore, is very limited and at this point only experimental.

Thus, the choice of the proper imaging technique requires fully understanding the potential of each, and their advantages and limitations. Ultimately, exam value is linked to the method used as well as the skills in performance and interpretation of the resulting images.⁹

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Postmortem Imaging: Methods and Techniques

Currently, forensic radiology is valuable in penal and civil litigations but most useful in personal identification, death and injury evaluation. However, forensic radiology starts with the correct choice of imaging technique that depends on the specific questions raised, its performance and interpretation and ultimately the report of the examinations and procedures to the courts.³

As Pomara et al stated almost 10 years ago: "... Legal systems around the world must accept the admissibility of imaging evidence in determining the cause and manner of death. Radiologists will also need special training in post-mortem imaging, as cadaver imaging is very different from imaging living patients. However, digital autopsy is and will remain merely an aid in the practice of forensic medicine and one that is not always available and that cannot be considered an alternative to conventional postmortem procedures."¹⁰

An interesting point of view was recently expressed by Adlam et al who reported that since different limits can be encountered in the conventional autopsy, from sociocultural and religious barriers, the development of noninvasive cadaver analysis could be a great option: in this sense, forensic radiology becomes of fundamental importance.¹¹ According to this statement, since imaging techniques applied in forensics came from the clinical radiology, their usage is related to their informative power. Even as newer and newer radiological methodologies are developed, it is possible to trace the evolution of imaging from the morphologic analysis to functional analysis (Table). This evolution passes throughout a scanning technology, already used in car industry similar to body scanners that can provide a surface scan of the body called photogrammetry.

If this technique can provide what forensics call "external examination," ionizing radiations can offer a deeper analysis of the corpse. In this sense, X-ray and multidetector CT can provide a tissue and/or organ analysis. At the end, MRI spectroscopy allows giving a biochemical pattern linked with some particular metabolites present in the brain to give a more accurate time of death. MRI inserts itself among these 2 latter characteristics, being able, with a different degree of spatial resolution, to also provide anatomical-morphologic information.¹²



Figure 1 X-ray in case of anonymous cadaver. Note the diffuse presence of air in the subcutaneous tissues.

In this review, we will focus on the latest developments in conventional radiology, CT, and MRI techniques for the field of forensics.

Postmortem Imaging: Conventional Radiology

Even if several techniques such as multiplanar and multi-parametric are used to investigate pathoradiological findings in cadavers, conventional X-ray deserves to keep its role as the first approach to the corpse analysis (Fig. 1).

Even though conventional radiography is the oldest technique used in forensic pathology, it has become widespread and still can provide easy answers to specific questions, without resorting to CT. Indeed, X-ray can delineate skeletal injuries, reveal the presence and localization of radio-opaque

Table Evolution of Forensic Information by Means of Imaging Techniques

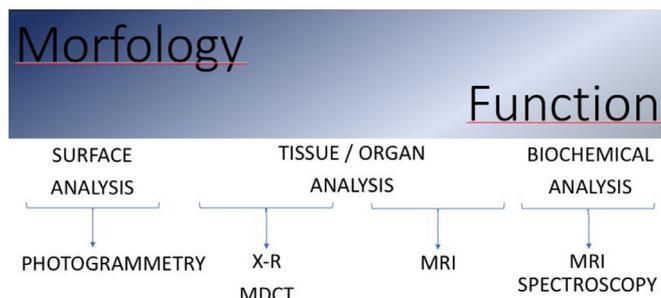




Figure 2 The specific healing outcome of the fibula and tibia fracture helped in the correct identification of the unknown body.

foreign bodies (such as gunshots), recognize anthropometric features, by bone analysis and dimensions, and help person identification, mainly by means of orthopantomography.

Therefore, conventional X-ray can provide quick skeletal tissue analysis, which can help in the identification of unknown cadavers. In [Figure 2](#), for example, the bi-osseous fracture outcome of the right lower limb provided useful information for identification.

However, X-ray accounts for several additional applications, among which the study of fetuses is one of the most important.

As recently indicated by [Sonnemans et al](#), postmortem MRI (PMMRI) is the modality of choice for the evaluation of fetuses while postmortem CT (PMCT) is advised in older children. For autopsy in neonates or infants, X-ray could represent the first step. For example, the whole-body radiograph of the fetus, which is a survey of the skeleton, also known as “babygram” allows for detection of bone abnormalities with high sensitivity and specificity that may suggest other, different genetic and lab investigations.^{13,14}

Another different indication for X-ray that has been recently suggested by [Zhang et al](#) uses pelvic radiographs to establish a regression model for age estimation from the combination of the ossification of both the iliac crest and the ischial tuberosity.¹⁵ [Zhang et al](#) suggested in 2015 that because the cadaver age estimation procedures have gained more significance currently, it is important to have a reliable tool to establish age by means of diagnostics; however, age related to skeletal maturation can differ depending on socio-economic status, ossification of the iliac crest apophysis could be a useful tool for age estimation.¹⁶ A different application of conventional radiology in forensics is the estimation of gestational age serving an important role in forensic

settings, particularly to assess fetal viability. For example, the length of the long bone diaphysis is one of the most frequently used methods for fetal age estimation. Based on radiographic images of 257 fetuses, [Carneiro et al](#) showed that measurements performed on the diaphyses of the femur, tibia, fibula, humerus, ulna, and radius provided models for the estimation of gestational age, and are of great applicability in forensic contexts.¹⁷

Finally, as mentioned above, another use of conventional X-ray is dental identification. This technique, most used in the ultrasound, allows to identify a person by means of comparisons between radiographs of the cadaver teeth with the dental radiographs obtained from the dental archives.¹⁸

Postmortem Imaging: CT and CT Angiography

The most revolutionary imaging technique introduced into forensic pathology is CT, which can provide multiplanar and 3D volume rendering reconstructions.¹⁹ CT is a relatively low cost, time-sparing examination that provides great diagnostic accuracy. Indeed, several advantages were recently reported by [Grabherr et al](#)²⁰ comparing postmortem CT and conventional autopsy in determining the cause of death. Recently, PMCT has been used to investigate injuries in burned victims. This special category of cadavers has such specific characteristics that radiologists need to acquire different diagnostic tools to properly analyze images. CT allows differentiation between the normal postmortem and heat-related changes that can help the forensic pathologist, either before or after the conventional autopsy, to answer some detailed questions aiding in police investigations. For example, [Coty et al](#) suggested that PMCT not only could allow the identification of a severely burned body with signs of traumatic vs heat-related fractures but also allow for the presence and precise localization of gunshot and/or ballistic foreign bodies in the burned victims.²¹

As shown in [Figure 3](#), PMCT has an important role in identifying the presence of bullet localized in the anterior part of the right thoracic cage. Specifically, this figure shows the anteroposterior scanogram, in which a hyperdense, metallic, foreign body is visible; in addition, 3D volume rendering provides a surface pictogram and bone reconstruction reveal a skull fracture, already appreciable in the scanogram. As demonstrated in [Figure 4](#), 3D volume rendering provides essential information for the forensic pathologist, providing a tridimensional view of the spatial orientation. For example, with multiplanar imaging with oblique reconstruction, the route of a bullet in the skull can be shown identifying the entry and exit holes ([Fig. 5](#)).

Postmortem imaging, also known as “virtual autopsy,” is a field that bridges forensic science and radiology, and has shown remarkable growth particularly in the postmortem investigation of trauma victims. In a recent review, [Jalalzadeh et al](#) evaluated the feasibility of PMCT as complimentary to and instead of conventional autopsy in a selected group of patients.²² The authors concluded that PMCT detection of skeletal injuries was more



Figure 3 Bullet identification in cadaver throughout 3D-VR reconstructions.

sensitive than conventional autopsy, while in cases of minor organ and soft tissue injuries, autopsy preserves its superior diagnostic accuracy as compared to imaging.

However, PMCT has poor discriminative power in parenchymal organs and in soft tissue because of early postmortem changes, but more importantly, PMCT is lacking in evaluating the vascular component of the cadavers.²³

Postmortem Imaging: Beyond CT

Because cardiovascular disease is already known as the major cause of death, the value of PMCT is limited in this regard.

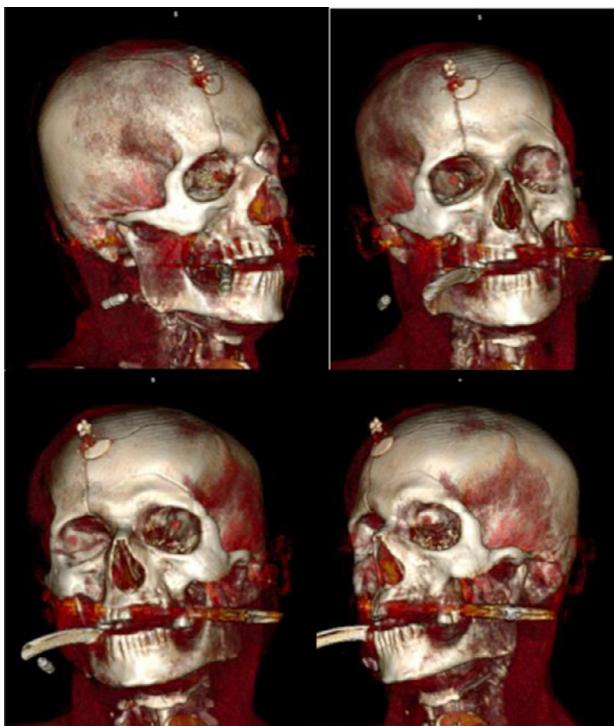


Figure 4 VR reconstruction in case of gun victim.

Consequently, artificial angiographic integration represents a significant advance in forensic radiology. Of the several techniques that have been developed, the most useful is the multiphase postmortem CT angiography (MPMCTA). More and more papers have been published about MPMCTA that assess its role in supporting conventional autopsy. Although



Figure 5 Multiplanar oblique-coronal reconstruction of the case in Figure 4. The image allows to verify the course of the bullet with entry hole in the skull and exit one in the left maxilla.



Figure 6 MPMCTA. Note in the lower part, on the right side, cannulas to pump oil-radio-contrast into the circulatory system.

in the future this modality may ultimately replace autopsy, presently it should be considered to have a complementary role in forensic pathology.

This approach uses a CT acquisition before, during, and after administering a contrast medium, after femoral artery and vein have been cannulated, as shown in Figure 6. Indeed, since postmortem circulation is not feasible, “two-step post-mortem angiography” was developed that consists of postmortem perfusion using a modified lung-heart machine.²⁴ The correct procedure includes standard protocol imaging by means of pumping an oil-based agent capable of filling the cadaver vascular tree but not spreading throughout tissues. The results are shown in Figure 7, where a

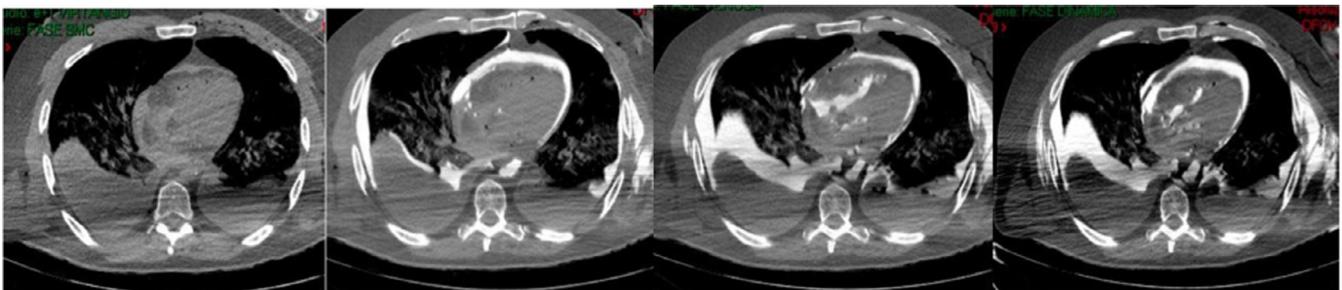


Figure 7 MPMCTA. From the left to right, the first CT acquisition without contrast, and then the results of consecutive acquisitions at different points after contrast injection.

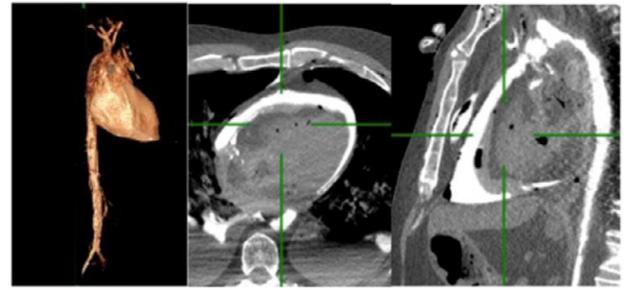


Figure 8 Spread of contrast into the pericardial sac and throughout the enhanced aorta.

multiphase contrast injection is demonstrated. For example, in this particular case of a car accident victim, the presence of the contrast in the pericardial sac can be highlighted (Fig. 8) to demonstrate an important aortic rupture with fatal cardiac tamponade.

This technique has demonstrated significant value in diagnosing causes of sudden cardiac death, such as disruption of coronary arteries, identification of vascular obstruction, or sources of fatal hemorrhages. The use of the contrast also allows for the detection of damage to soft tissues or parenchymal organs. The sensitivity of this method has been favorably compared to that of the conventional autopsy. More importantly, MPMCTA has shown to be useful in forensic science, particularly in cases of acute bleeding and hemorrhage, ischemic heart disease, and pulmonary thromboembolism. In these circumstances, MPMCTA has an overall sensitivity ranging from 64% to 81%, sensitivities that appear to be increasing.²⁵ Indeed, while identifying the source of bleeding during a conventional autopsy can be a great challenge, PMCT can provide answers by revealing the origin of this fatal circumstance.^{26,27}

Recently, this technique has also been shown to be useful in the characterization of stab and gunshot injuries. With extravascular and external local applications of contrast media, it may be possible to reconstruct stab directions and to document the inflicted wound depth.²⁸

Nevertheless, there needs to be awareness of 3 main groups of pitfalls of MPMCTA:

- Incomplete venous opacification of the head and neck vessels.

- Artifactual contrast enhancement or extravasation into the gastrointestinal tract.
- Contrast layering in the nondependent aspect of vessels or incomplete filling of the arterial or venous system.²⁹

Radiologists need to familiarized themselves with these artifacts and pitfalls as to their type, anatomical localization, and timing of appearance to avoid misinterpretation.³⁰

For example, in the case shown in [Figure 9](#), an abnormal enhancement of the esophagus and trachea with bronchi is visible after injection of the oil-based contrast agent, indicating to represent an arterio-esophago-respiratory fistula as the cause of death confirmed at autopsy.

Currently, a new field of interest is the visualization and identification of myocardial infarction ([Fig. 10](#)). In this regard, Sabatasso et al recently published an interesting feasibility study demonstrating that MPMCTA was able to depict pathologic enhancement of the myocardium to allow correct diagnoses while comparing 10 autopsy cases with a control group all that underwent to MPMCTA.³¹ The authors detected myocardial enhancement in all cardiac death cases, exactly where histology identified typical pathologic findings of infarction, while in control cases no abnormal enhancement was revealed.

These results have important implications in the routine management of sudden cardiac death cases. In fact, MPMCTA can not only suggest the cause of death before autopsy but also can help identify affected regions to guide and improve sampling for microscopic examination.

A more specific and detailed MPMCTA has been developed to study coronary vessels. Thanks to a very fast device, a large number of data and images can be acquired in a short time so that it is possible to analyze coronary vessels and to visualize all the various stages of a myocardial infarction. This technique is so useful in investigating coronary artery

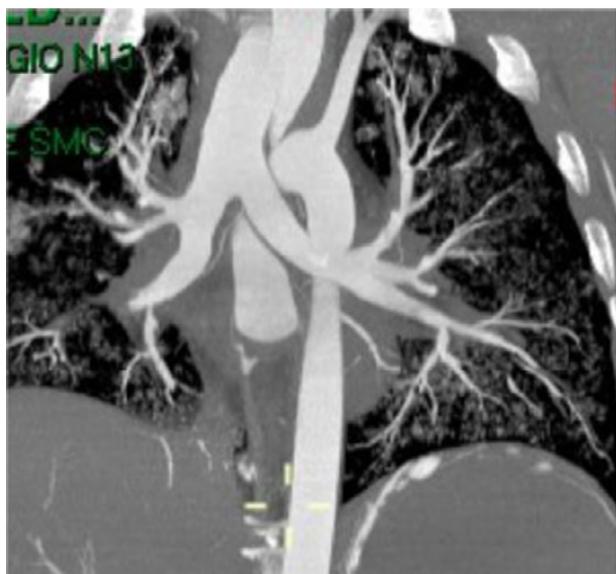


Figure 9 Abnormal presence of contrast in the tracheobronchial tree and esophagus.

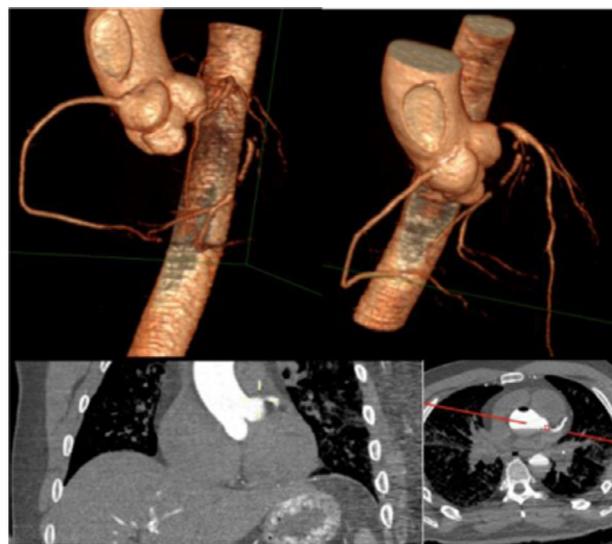


Figure 10 Coronary angio-CT showing almost complete occlusion of the proximal part of the common trunk of left coronary artery, which had caused an extensive myocardial infarction.

pathology that postmortem cardiac CT may able to provide near-histologic levels of myocardial, coronary, and valvular detail.³²

In several contexts, it may be important to obtain accurate imaging detail of the coronary arteries. PMCT and PMMRI represent the most useful approaches, allowing a minimally invasive but advanced autopsy, integrating the great spatial resolution that is limited in PMMRI, with contrast resolution that is limited in PMCT. Notwithstanding the value of these newer imaging techniques, the role of forensic pathologists remains crucial, because it is currently not possible to ascertain at a microscopic level the histologic representation of tissues, essential for a specific diagnosis such as in cases of coronary plaque rupture or coronary dissection. However, newer technologies can provide a supplementary tool, coronary optical coherence tomography. This method that is occasionally used during percutaneous coronary interventions provides a high-resolution coronary image furnishing a sort of virtual histology. Even though this technique has not yet found a definite place in minimally invasive autopsy practice, there is some experimental work that is endeavoring to apply it with a high diagnostic potential.¹¹

A new modality for forensic investigations is microfocus CT also known as micro-CT. Traditionally used in preclinical studies, this imaging technique has found a new applicability in the routine clinical setting, providing a complete data set of images that can offer a 3D high-resolution reconstruction with same level of detail as microscopic examination.³³ Micro-CT is an interesting and novel approach in the noninvasive assessment of specimen and cadavers, particularly useful in the early gestation fetal autopsy. Moreover, gunshot residue on the skin surface around the entrance hole, even on dermis layer in decomposed bodies, can be detected by this technique according to recent work by Fais et al.³⁴ Lastly, using its affinity for calcified tissues, this technique could help in the visualization of coronary vessels.³⁵

In a recent article, Busardò et al pointed out that PMCT has achieved a fundamental role in the forensic diagnostic approach to the cadaver and being routinely requested that provides the chance to store and revise images at any time going beyond the diagnosis that can be made by conventional means.³⁰

Postmortem Imaging: MRI

As already reported, ionizing radiation techniques should be considered methods of the first choice in localizing foreign bodies, evaluating fractures and gases, but PMCT and MPMCTA play central roles in forensic radiology. However, all these imaging approaches have limitations, particularly in assessing soft tissues alterations and internal organs changes.

MRI, on the contrary, because of its imaging features can characterize soft-tissue injuries and pathologies clearly.³⁶⁻⁴² Without the need for ionizing radiation, MRI can be used, for example, to examine living victims of assault, particularly in cases of manual strangulation, highlighting neck muscle hemorrhages or perifocal hematomas surrounding fractured laryngeal structures.

Recently, Ahmad et al have investigated the role and the diagnostic accuracy of PMMRI as an alternative to autopsy. In the systematic review and meta-analysis, the authors explored the field of the newly trusted MRI virtopsy to investigate the cause of death.⁴³

To compare the possible use of MRI virtopsy to the traditional postmortem examination, a systematic review was made, including 5 studies with 107 bodies, contributed to a summative quantitative outcome in adults. The results showed an extraordinarily high sensitivity that reaches to 0.82 but with a large confidence interval at 95% ranging from 0.56 to 0.94. The authors concluded that even if MRI virtopsy may offer a viable alternative to the traditional autopsy, its potential should be determined from time to time to achieve optimal results.

There are important drawbacks to PMMRI. As Bolliger et al discussed in its recent article, there are 2 major implications that concern PMMRI use in practice, 1 of which can be summarized in the syntagma of “cost-effectiveness.”⁴⁴ It still remains costly to perform an MRI, and its use has to be seen mostly in the framework of a health care service. Another drawback is that the real potential benefit of MRI has yet to be conclusively demonstrated.

Nevertheless, further research is required to offer better evidence, especially for adult studies. Knowing what we already know, it is possible to imagine what technology will be able to do in the future, revealing new clinical applications of this novel and emerging technique.

Conclusions

In clinical radiology, the diagnostic hypothesis is addressed to a specific question and supported by physical examination. In postmortem imaging, however, even if circumstantial

information and external examination are useful, they are often insufficient, and all radiological images must be read very carefully because they may be relevant for case reconstruction.

The collaboration between the radiologist and forensic pathologist is pivotal in legal settings where each case should be discussed in detail, the most useful imaging technique (X-ray, CT, and MRI) must be chosen and techniques should be used to minimize artifacts due to postmortem changes.

Another important issue is developing the scenario of the postmortem imaging examination, such patient data, manner of death, including or excluding third-party negligence.⁴⁴

Postmortem imaging was developed as a new subspecialty combining the expertise of both forensic pathology and radiology.⁴⁵ Unfortunately, a specific curriculum in this field is not as yet available but because of the compelling need of radiologists and forensics, in 2013 the International Society of Forensic Radiology and Imaging was founded. As reported by Flach et al, it is not inconceivable that in the near future, radiologists will work side by side with forensics pathologists, not only performing and reading radiologic images but also attending autopsies and carrying out or supporting forensic inspections.⁴⁵ One of the main challenges of the coming years will be to unify these 2 branches of medicine to improve communication, to improve exchange of information and to create a pathophysiologic foundation of imaging evidence in the field of postmortem imaging.⁴⁶

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