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PEDIATRICS (L AVERILL, SECTION EDITOR)

Pediatric Postmortem CT: Initial Experience at a Tertiary Care Children's Hospital

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Abstract
Purpose of Review Pediatric postmortem imaging is a new and rapidly growing discipline. A review of recent literature is discussed along with a brief overview of common imaging findings on postmortem CT that may simulate antemortem pathology.
Recent Findings The authors describe their own experience in establishing a postmortem imaging program as well as a discussion of the unique challenges in developing a program and performing and interpreting postmortem CT.
Summary Postmortem CT may provide valuable information in understanding the cause of death and disease processes in children; however, collaboration and research are needed to confirm the reliability of postmortem imaging diagnoses and to differentiate postmortem processes and antemortem pathology.

Keywords Pediatric postmortem imaging · Postmortem CT · Antemortem pathology

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Introduction

Our institution has experienced a decline in hospital-based autopsy from 50% of in-hospital deaths in 1997 to 18% in 2006. While autopsies have always been important to understand disease and death, they are becoming increasingly uncommon [1–6]. Autopsies are now performed at a rate between 5 and 30% worldwide. The decline is attributed mainly to cost and reluctance of families to consent. Subsequently, there is growing interest in the use of postmortem imaging (PMI) to complement or even substitute for more invasive autopsy evaluation [1, 2, 7]. In the pediatric age group, PMI is a very new discipline without established best practices or imaging protocols [1–5, 7–9, 10•, 11]. In addition, most radiologists are unfamiliar with expected postmortem changes [12, 13••], and these changes can be challenging to differentiate from antemortem pathology [13••, 14••, 15••]. This article will describe our experience in developing pediatric postmortem imaging at our institution.

Background

X-rays have been used for over 100 years for postmortem and forensic evaluation [16]. In pediatrics, skeletal surveys are routinely used in addition to autopsy for suspected fracture, skeletal malformation, or skeletal dysplasia [4, 7, 16]. Postmortem CT (PMCT) was introduced in adults in the 1970s and 80s for forensic use [10•, 16] and for autopsy, respectively [16, 17]. More recently, multidetector CT (MDCT) technique has replaced single-detector technique for PMI with the opportunity to create multiplanar reformatted images and 3-dimensional volume-rendered images for improved diagnosis of skeletal

Table 1 NAIDHC postmortem CT technique—Siemens Force dual-energy CT

Age	Body part	kV	Effective mAs	Quality reference mAs	Pitch	FOV (cm)
<8 months	Head/spine	120	110		0.6	16
	Head to pelvis	120	110		0.6	16
	Ears through toes	120	480		0.4	32
	Each upper extremity separately	120	480		0.4	32
	Lower extremities together	120	480		0.4	32
9 months to 5 years	Head and C-spine—dual energy	80/140		264	0.7	16
	Ears to toes—dual energy	80/140		264	0.7	32
	Trunk to include upper extremities	120	480		0.4	32
	Pelvis to toes	120	480		0.4	32
5 years and up	Head and C-spine—dual energy	80/140		290	0.7	16
	Ears to pelvis—dual energy	80/140		290	0.7	32
	Pelvis to toes	140	400		0.4	32

pathology [13••]. In 1994, postmortem CT (PMCT) was first described as a potential substitute to autopsy [18]; however, the authors did indicate that a combination of autopsy and imaging would be most accurate. With the expansion of MDCT, PMCT has become standard practice in some institutions worldwide [16]. Postmortem CT angiography (CTA) [17, 19, 20] and ventilated PMCT [21] are two extensions of PMCT technique that have been reported, as well. Postmortem ultrasound [4, 22–24] and magnetic resonance imaging (PMMRI) [4, 5, 13••, 25] are also utilized for evaluation to supplement autopsy findings in some institutions.

A postmortem imaging program was developed at our institution to perform PMCT and PMMRI as an adjunct to the Delaware Office of the Medical Examiner (DOME) medicolegal death investigations as well as to in-house medical autopsies. One of the authors (HTH) has extensive experience in adult postmortem imaging and forensic radiology and has assisted the DOME with unexplained pediatric death or suspected non-accidental injury cases and proposed this program. The DOME and the hospital departments of Medical imaging and Pathology collaborated to develop the program with the goal of finding additional information regarding the cause of death in these cases. We have also looked at emergency medical interventions and provide clinicians with feedback regarding interventions undertaken by first responders and our emergency medicine department.

Technical Considerations

There are many procedural considerations involved in the development of a postmortem imaging program. In devising our CT protocols, we consulted with radiologists experienced in PMI and reviewed the available literature [10•, 26]. High dose, very high resolution technique is necessary for PMCT for multiplanar reformatting and 3D rendering to aid in detection of fractures and to minimize artifact. Our protocol (Table 1) uses multiple runs with both the 16-cm field of view for the brain and cervical spine as well as the 32-cm field of view for the whole body. All scans are performed with 0.6-mm collimation to provide isotropic voxels for reconstruction. Because radiation dose is not a concern, with smaller infants we use the 16-cm field of view to scan the entire spine, each individual upper extremity, and the lower extremities for improved resolution. We create detailed, segment-specific multiplanar reconstructions and 3D volume-rendered images (Fig. 1). Protocol development is an ongoing process with valued input and assistance from our technologists. We have been working with other institutions in the state of Delaware with the goal of achieving a statewide standard of practice for the PMCT protocol.

Postmortem imaging may be requested by the inpatient service, the emergency department in sudden death or trauma cases, by genetics for a stillbirth or medical termination, or by the medical examiner (ME). For all requests except those from the ME, consent from the family is necessary [27]. Most of our cases have been referred by the DOME, with only a few cases arising from the emergency department and intensive care unit (Table 2). Because in-house cases require consent from the family, we worked with the pathology department to develop a consent form that includes selections for postmortem imaging or non-invasive autopsy, including CT and MRI, in addition to or in lieu of autopsy. Counseling is given that the combined investigation is felt to be the most comprehensive.

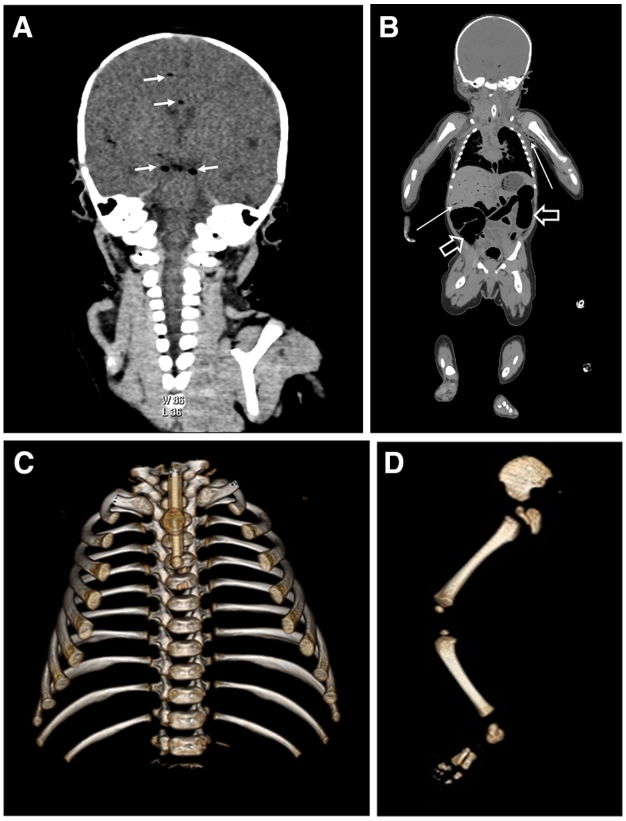

Fig. 1 This 4-week-old female was referred by the medical examiner for unexplained death. The actual time of death was unknown. Co-sleeping was suspected as no evidence of trauma was identified. **a** This is a coronal reformatted brain image scanned with the 16-cm field of view (FOV). Evaluation of the brain and cervical spine is always performed with the 16-cm FOV for optimal detail. In very small infants, the entire body can be imaged this way. Note the gas in the brain (*short white arrows*) that represents early putrefaction and which is an expected finding. **b** The entire body is then scanned with a low pitch and reconstructed with overlapping 0.6-mm slices for optimal reformatting like this coronal image. In very large patients, the upper extremities may have to be scanned separately if they do not fit in the initial whole body scan. Note the gas in the liver and left axilla (*long white arrows*) representing expected postmortem change. Mild gaseous distension of bowel is also present (*white open arrows*), and represents expected postmortem change. 3D volume-rendered images and multiplanar reformatted images of the entire skeleton are made in segments for improved assessment of trauma—**c** ribs, **d** right lower extremity. No fractures were identified

Table 2 Demographics of patients scanned at NAIDHC from 2011 to 2017

Number of patients	60
Age <1 year	41
Age <5 years	52
Referred by medical examiner	53
Referred by emergency department	3
Inpatient (ICU)	3
Exhumed	1
Post autopsy or organ harvest	6

Fig. 2 This 11-month-old female died after sustaining massive head injuries from a motor vehicle accident. The scan was obtained 2.25 h postmortem, and 3.75 h after the accident. This image through the chest shows gas in the right atrium. Gas (*black arrow*) may accumulate in the cardiovascular system after death due to autolysis with release of gas into the lumen, but is also reported as a common finding after cardiopulmonary resuscitation (CPR), which this patient had received. The *arrowheads* indicate thickening of the left ventricular myocardium, an expected finding due to muscle stasis. There is a hematocrit level in the left ventricle (*white arrow*), also due to stasis. The right heart will also enlarge (*open arrow*), again due to stasis. It is important not to mistake these findings for antemortem disease

Before beginning the program, we consulted with the technical staff regarding the timing of PMCT scans. To minimize decomposition changes, PMCT is ideally performed as soon as possible after death; however, timing is subject to decisions regarding scanner availability and transport of the body [3]. In addition to scans performed shortly after death, we have performed exams after organ harvest, after autopsy, or even upon exhumed remains to provide skeletal evaluation. Discreet transport of remains through public areas is also a consideration. We have worked with the technologists to devise a protocol for transport, minimizing contact with other patients and families. Our technologists' input has been invaluable in developing and improving our policies and imaging protocols. Support for the technologists is important [3] both with regard to training as well as counseling, if needed. The numerous, exacting reconstructions can be time-consuming and burden already busy staff, and the circumstances surrounding some of the patients can be upsetting.

Image interpretation requires training, planning, and collaboration [3, 5, 6, 12, 28]. Even when imaging is obtained promptly after death, the decomposition process and related findings must be differentiated from

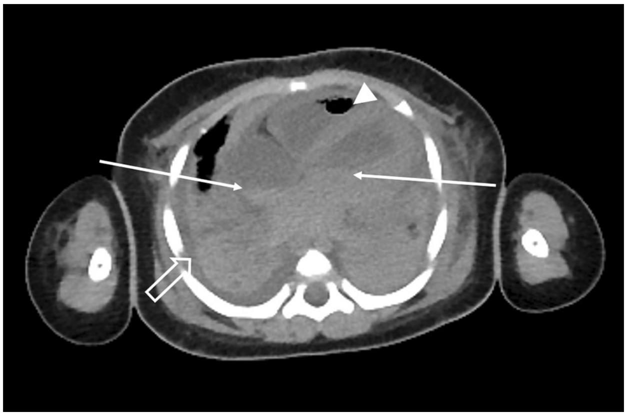

Fig. 3 The medical examiner referred this case of unexplained death in a 4-month-old male infant. Pleural fluid (*open arrow*) and gas in the right ventricle (*arrowhead*) and may represent expected postmortem changes due to livor mortis and putrefaction, respectively, and cannot be assumed to represent pathology. There is a hematocrit effect in the heart (*arrows*) due to stasis of blood and settling of solid blood components. The interval between death and imaging is unknown due to unknown time of death

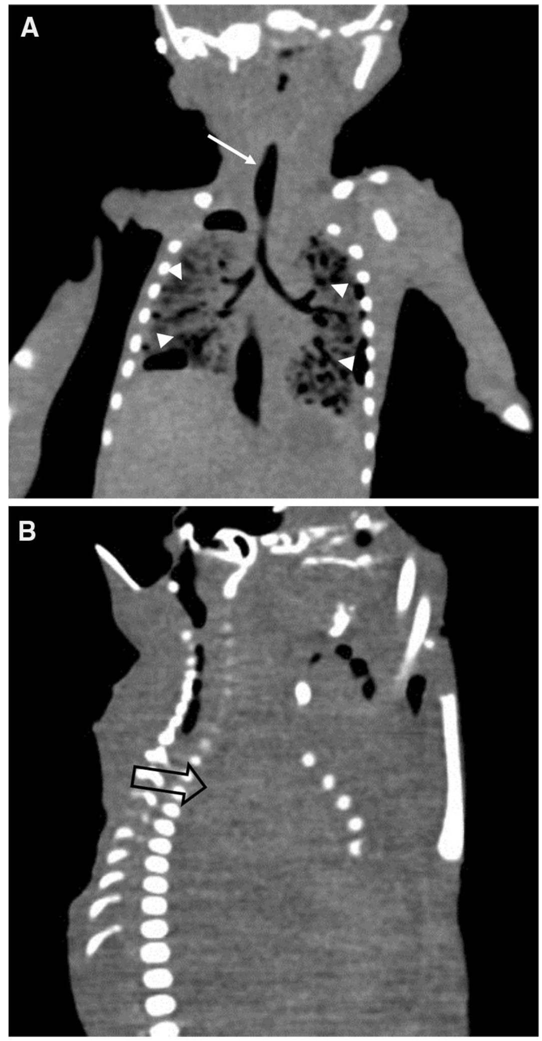

Fig. 4 **a** This coronal reformatted CT image of a 24-week fetus demonstrates gas in the trachea (*white arrow*) and lungs (*white arrowheads*), a finding that suggests the infant inhaled at birth. **b** This oblique coronal reformatted CT image of a 22-week fetus reveals no gas in the thorax (*black open arrow*), likely because the fetus was truly stillborn. However, it is possible for infants born in water to aspirate fluid rather than air and so no gas would be found in the lungs and airway. Correlation with history, if known, as well as with histopathology may be useful for corroboration

antemortem pathology [13••, 14••, 15••] (Figs. 2, 3). As we have begun interpreting PMCT cases, we have worked with one of the authors (HTH), an experienced pediatric radiologist and adult postmortem imager, to develop our knowledge and recognition of CT findings related to expected postmortem changes. Collaboration with pathology or the medical examiner is often needed because expected postmortem changes may resemble antemortem pathology [3, 6]. The timing of image interpretation is also a factor that must be considered [3]. Decisions should be made in advance regarding studies that are imaged late in the evening or on weekends given the exacting nature of the review required for interpretation. Our cases are often scanned at night and interpreted within 1–3 days.

Clinical Applications

There are a variety of situations in which PMI may help evaluate the cause of death in a child. PMI may help confirm prenatal findings or identify undetected underlying disease in the case of stillbirth, abortion, or neonatal death [5, 7]. In skeletal dysplasia cases, bone morphology can be assessed postmortem in greater detail than with prenatal imaging [4, 29]. Parental understanding of the disease process can help with bereavement as well as with genetic counseling [2, 4]. In fetal and neonatal death, PMCT may be best for skeletal and lung assessment. PMCT can identify even very small amounts of air in the airway and lungs of a neonate to differentiate between live and still birth [6, 30] (Fig. 4). PMMRI may be more useful for cases with suspected CNS, cardiac, or visceral abnormality.

PMCT is useful for detecting fractures or intracranial hemorrhage suspicious for non-accidental trauma in the setting of unexplained infant death [7] (Fig. 5). Finding the cause of death is more problematic in the absence of signs of trauma, however, because lung and brain pathology and expected postmortem changes can be difficult to differentiate on PMCT [13••, 14••, 15••]. In older children, PMCT can also be used for assessment of unknown trauma or previously undetected disease in the case of sudden death (Fig. 6). PMCT may even help determine the time of death [9]. PMCT is also helpful to assess cause of death and to

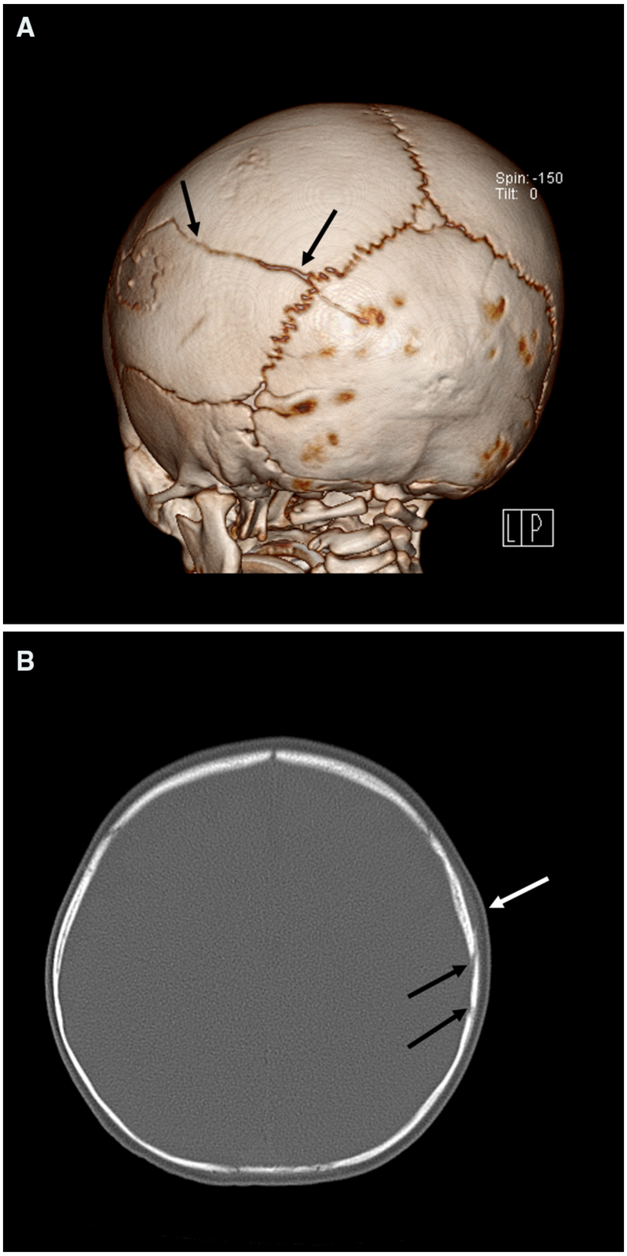

Fig. 5 This 6-month-old female was referred by the medical examiner for unexplained death. The interval between time of death and imaging was estimated to be 3–7 h. **a** A 3-dimensional (3D) volume-rendered image of the skull viewed obliquely from the left posterolateral aspect shows a non-depressed parietal skull fracture (*black arrows*) that extends across the lambdoid suture into the occipital bone. A 3D volume-rendered skull is created to maximize the chance of detecting a subtle skull fracture. **b** An axial slice through the left parietal region again shows the fracture (*black arrows*) as well as adjacent soft tissue changes (*white arrow*) just anterior to the fracture, indicating that the fracture is recent enough to still have associated soft tissue swelling in this case of non-accidental trauma

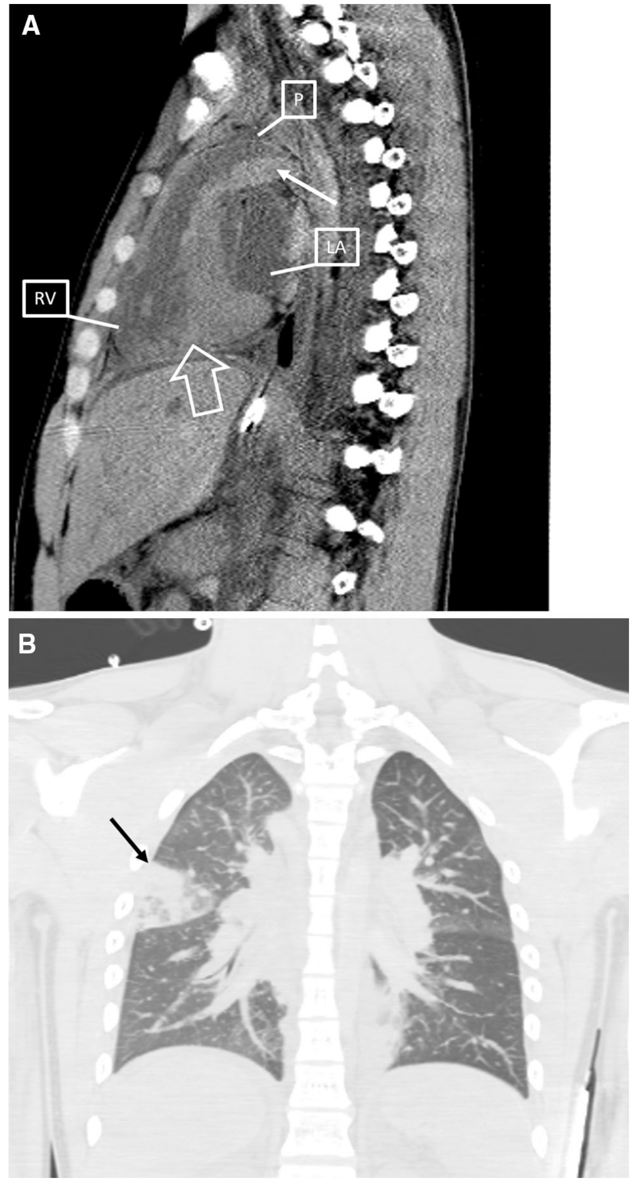

Fig. 6 This 15-year-old male had experienced a sudden flare of nephrotic syndrome and died in the intensive care unit following syncope with seizures and cardiac arrest. The scan was obtained 4 hours postmortem. **a** This sagittal reformatted image with soft tissue windowing through the mediastinum shows a central, hyperdense filling defect representing a saddle pulmonary embolism (*white arrow*) in the main pulmonary artery (P) and right and left branches (not shown). There is a hematocrit effect (*open arrow*) visible in the right ventricle (RV) (LA—left atrium). **b** A coronal reformatted image of the chest windowed for the lungs shows a wedge-shaped opacity indicating a pulmonary infarct (*black arrow*). The asymmetry of the finding raises suspicion for antemortem pathology and can help direct the autopsy

detect unsuspected pathology in medically complex patients. PMCT may identify complications of medical interventions [19, 31] and clinically unrecognized conditions, as well as providing a non-invasive evaluation of support device placement for educational purposes (Fig. 7).

In our experience so far, the cases referred by the DOME have usually involved unexplained infant death

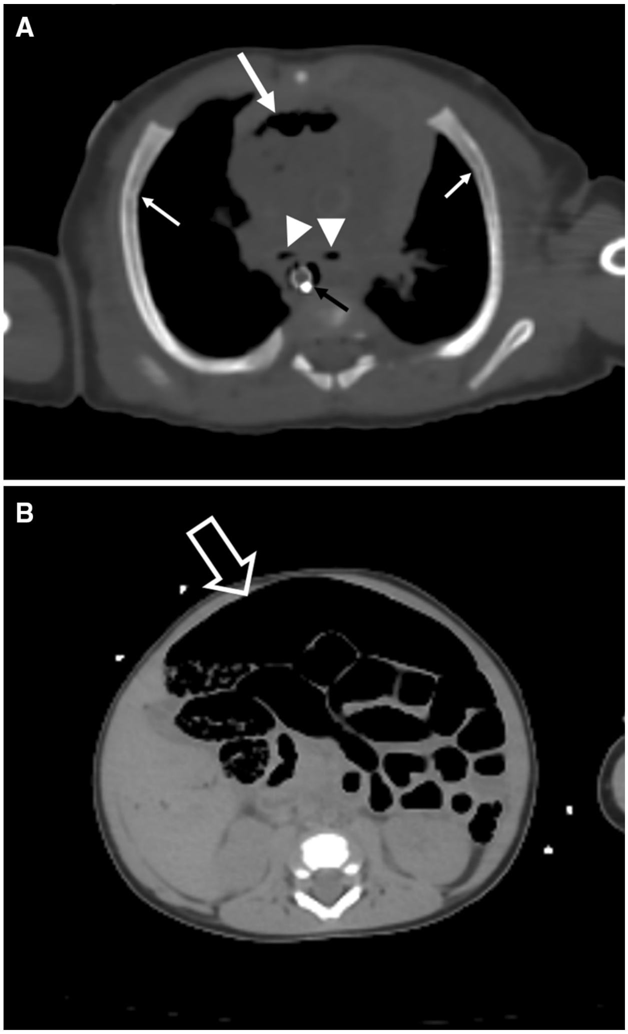

Fig. 7 CT was performed at an unknown interval postmortem in this 8-month-old male who was status post attempted cardiopulmonary resuscitation (CPR). **a** An axial image with the bone window setting shows intracardiac gas (*large arrow*) which has been described in deceased patients after CPR. Inadvertent esophageal intubation is identified (*black arrow*) (*arrowheads*—right and left mainstem bronchi). There are subtle, buckle fractures of the anterolateral aspects of the 5th ribs, bilaterally, along their inner cortices (*small arrows*). Fractures in this location are known to be associated with CPR, whereas posterior rib fractures are not. **b** There is pronounced gaseous dilatation of bowel (*open arrow*) on an image through the mid-abdomen presumably due to esophageal intubation

with the need to evaluate for non-accidental trauma. When we identify abnormalities that do not conform to expected postmortem change, our findings guide more in-depth gross and histopathological analysis (Fig. 8). Within the last year, we have begun to offer PMMRI in addition to PMCT for improved detection of CNS and soft tissue findings. We understand the limitations of PMCT in cases of natural death, noting that PMMRI may offer improved imaging in some cases [6]. So far, PMCT has been useful for identifying pathology not otherwise detected by standard autopsy, particularly in the skeleton, as well as for assessment of medical intervention (Fig. 9).

Fig. 8 A coronal reformatted image from a PMCT performed on a 4-month-old male with unexplained death shows fluid accumulation in the pleural and peritoneal spaces. Fluid is present in the pleural spaces, bilaterally (*arrows*), but there is a much larger amount of peritoneal fluid (*open arrow*). While fluid accumulation is expected postmortem, it should be low volume, fairly symmetric, and uniform. In this case, the findings suggest antemortem pathology and should prompt further investigation of the peritoneal cavity

Challenges

Because pediatric PMCT in children is a very new field, there are few radiologists experienced in both pediatric/fetal imaging and postmortem/forensic imaging [12, 13••]. We were fortunate to have a contact (HTH) with extensive experience to help develop the program as well as train both radiologists and technologists. Even so, collaboration between radiologists and pathologists is often needed. Our interpretation of findings is limited by the need for ongoing research to verify the reliability of imaging findings in the postmortem setting [5, 7, 22, 32, 33••]. Correlation with autopsy findings is therefore needed as well as communication regarding imaging findings [22] as standard terminology has not yet been developed [1, 11].

There are no best practice standards, as yet [10•, 34, 35] and so we have tried to standardize our protocols and share them with other institutions to improve the uniformity of image quality. Although imaging techniques have been described and task forces in North America and Europe have been formed to develop standards for PMI, more investigation is needed in general to identify best practices [10•, 22, 26, 33••, 36]. Standards have not yet been

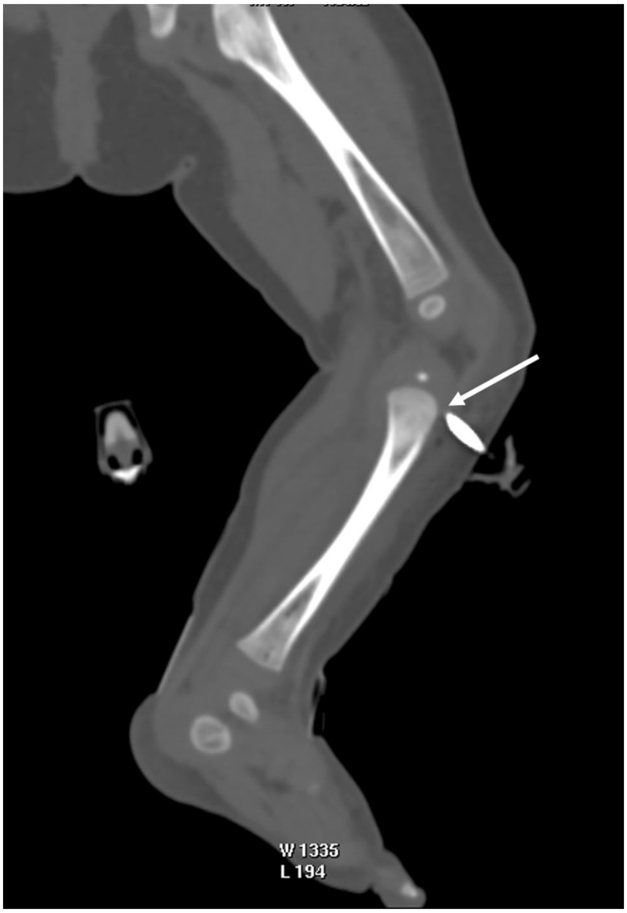

Fig. 9 In this oblique reformatted image of the left lower extremity in a 4-week-old male with unexplained death, the interosseous cannula tip (*small arrow*) is seen anterior to the tibial cortex and not entering the bone. PMCT can be useful for training and performance improvement for emergency medical technicians and hospital staff

developed regarding the most suitable imaging protocol for different clinical situations, for example suspected non-accidental trauma versus death of a medically complex child [1, 5, 7, 22]. As stated above, we are instituting PMMRI, but have not yet developed algorithms for which modality is most appropriate in which setting.

We are currently not reimbursed for PMI requested by the DOME. Reimbursement in general for PMI is undecided [3, 11, 22, 28]. Justification of a non-reimbursable study to a hospital or imaging center administration is a challenge [12]. If no compensation is provided, institutions may be unwilling to support development of a PMI program.

Conclusion

Beginning a postmortem imaging program de novo requires extensive advanced planning from consent to transport to scanning technique to interpretation. Significant interdisciplinary collaboration is necessary to provide this service in an efficient manner without disruption or distress for living patients and the technical staff. The importance of technologist training, cooperation, and input cannot be overstated. Training for the radiologists interpreting these studies is needed as well, most importantly in terms of recognition of expected postmortem changes. Again, cooperation with pathology and the medical examiner, when appropriate, is needed to corroborate findings and to learn to recognize postmortem change. The input of clinicians will be needed as well to correlate antemortem clinical pathology with postmortem findings.

Postmortem imaging in children is a rapidly developing field with many unknowns. The potential exists to provide additional insight into the cause of death in a child either as an adjunct to autopsy providing complementary information, or in lieu of autopsy for families opposed to a more invasive assessment. The additional insight gained may help with bereavement and genetic counseling [27, 37, 38]. It may also assist the judicial system providing evidence of non-accidental trauma [10•]. Archived data from a PMCT can be reviewed long after the autopsy and can be de-identified for consultation and collaboration [16, 26]. In a courtroom setting, visual display of imaging findings can provide confirmation of injuries without the need for gross photography [16]. Instruction of first responders, emergency personnel, and surgeons can be given with regard to support devices and surgical interventions [19, 31, 36].

To realize the possible beneficial impact of PMI, the value of imaging in addition to, or even in lieu of, autopsy must be proven. Major error rates in PMI in adults range from 32 to 50% [5, 16] with the most common errors involving cardiac ischemic disease, pulmonary embolism, and pneumonia. Laboratory data and microbiology correlation are needed in many cases examined with PMCT to determine the cause of death [4, 22]. Evidence is limited that PMCT is superior to radiographs [4, 22, 39], even though it provides very high-resolution bone imaging. PMCT has been found to be better than X-ray for rib fractures in one study [40]. As the number of papers describing imaging findings that can be ascribed to specific antemortem pathologies increases, the value of PMCT will grow and PMCT will even guide the autopsy in some cases [33••]. It remains important that the relative limitations of PMCT are explained when it is offered to families in lieu of autopsy [4, 5, 27]. To establish the place of PMCT in postmortem investigation, radiologists must prove that postmortem imaging is both reliable [32] and valuable [41]. At this stage, ideal postmortem imaging evaluation might include PMMRI for the CNS and soft tissues, PMCT for lungs and skeletal structures and directed autopsy as imaging will never replace histopathological analysis. PMCT has the potential to provide valuable information, but should be undertaken with full understanding of its capabilities and limitations.

Compliance with Ethical Guidelines

Conflict of interest Sharon W. Gould, M. Patricia Harty, Nicole Givler, Theresa Christensen, and Howard T. Harcke each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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