National Association of Medical Examiners Position Paper: Postmortem Assessment of Suspected Head Trauma in Infant and Young Children

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Abstract

The National Association of Medical Examiners (NAME) convened a panel to create a position paper for the investigation of pediatric deaths due to suspected inflicted head trauma. The certification of both the cause and manner of death is dependent upon an evaluation of all available data including information derived from the investigation, scene, postmortem examination, and ancillary studies. This paper provides the forensic pathologist with a comprehensive review for the postmortem examination of infants and toddlers who have died or have apparently died of inflicted head trauma. Specifically, this paper describes (1) procedures, (2) ancillary laboratory tests, and (3) forms of documentation that may be important in the investigation of these deaths. Some of these techniques are highly specialized and are performed at the discretion of the prosector. The evaluation and documentation of such fatalities involves the production of a reviewable, objective dataset to support the multitude of inquiries that may follow from the public and the criminal justice system.

Keywords: Forensic pathology, head trauma, infant, homicide, autopsy

Introduction

The National Association of Medical Examiners (NAME) was founded with "the dual purposes of fostering the professional growth of physician death investigators and disseminating professional and technical information vital to the continuing improvement of the medical investigation of violent, suspicious and unusual deaths."(1) One method of fulfilling this mission is the publication of autopsy standards (2) and position papers.(3-5) NAME has previously published position papers on a variety of topics including the investigation and certification of cocaine, heat-related, in-custody, pediatric environmental neglect, and opioid deaths.(3-12)

Fatalities that may be the result of inflicted head trauma in the pediatric population are some of the most challenging investigations for a forensic pathologist, particularly when abnormalities are limited to the head and/or the circumstances of death are not clear.(13) Complementary to a thorough medicolegal death investigation, the goal of the forensic autopsy is not only to aid in the determination of the cause and manner of death, but also to produce a dataset that allows the original forensic pathologist (and others who follow) the best opportunity to independently review primary data and potentially answer reasonably foreseeable future questions.

Infants and young children die suddenly and unexpectedly for a myriad of reasons that span the spectrum from disease to inflicted injury.(14, 15) Infant/childhood deaths due to head trauma may have no history of injury and no external evidence of trauma. Therefore, unexpected pediatric deaths are carefully and thoroughly evaluated at all stages of investigation to ensure that the forensic pathologist recognizes, documents, and considers all relevant data so that they can appropriately make diagnoses that may be disease and/or trauma related. As pathologic findings emerge during the examination, evisceration, and prosection, the necessity and/or utility of ancillary dissections and studies will become apparent, and their selection can be tailored by the forensic pathologist.

The following describes a progression of examinations and processes for the description and documentation of autopsy findings (see Table 1). Although the focus of the paper is on the central nervous system, the detection and documentation of other disease processes and injuries involving the torso and extremities also are described. While we describe the steps for the autopsy, we do not discuss the interpretation or usefulness of specific findings. Determination of the manner of death involves interpretation of the autopsy findings in the context of the circumstances of the death.

Autopsy protocols have been developed for cardiac, metabolic, and sudden infant deaths (14, 16-24) to promote both consistency and comprehensiveness in examinations which are designed to evaluate for a broad range of possible disease states. Similarly, this paper aims to describe autopsy procedures that produce a reviewable, objective dataset for pediatric deaths that may have been due to head trauma. NAME has created general autopsy standards that are applicable to infants and children with apparent head trauma.(25) This position paper does not create new standards nor is it meant to expand or replace those pre-existing standards but rather to describe additional techniques, procedures, and other considerations that may be useful for these investigations. Each case is unique, and these procedures are not meant as a substitute for professional judgment in any one case. It is not meant to promulgate rigid criteria and inflexible rules which absolve forensic pathologists of the responsibility to think critically. Some of these techniques are highly specialized and are performed at the discretion of the prosector depending on the details and context of the specific case. One cannot anticipate every variable and contingency that may exist in a specific case which could reasonably affect the extent of an autopsy dissection. Therefore, its use is best tempered through the recognition of physical and investigative context, and the specifics of each case.

Steps Taken Prior to Autopsy

As described in the NAME autopsy standards, full-body photography and radiographic imaging are performed prior to the physical evaluation.(25) In order to avoid loss of evidence and/or contamination, it is recommended that trace evidence collection (including performance of a sexual evidence kit) is done prior to handling and washing the body in accordance with the requirements of the crime laboratory procedures.(25, 26)

Digital Photography:

High quality color photography is integral for documentation and facilitates case review by others (Table 2).(25, 27-31) External surfaces of the body are photographed with close-up photographs of specific findings and injuries (e.g., abrasions, contusions, lacerations, etc.) with a ruled scale as per the NAME standards.(25) For certain injuries (e.g., patterned injury), the American Board of Forensic Odontologists (ABFO) ruler photographed at 90 degrees from the camera lens can assist with later comparisons as the photographed scale is only relevant to those findings that are in the same plane as the ruler. Internal photographs typically include both pertinent positive and negative findings of tissue planes (e.g., undersurface of the scalp, anterior chest and abdominal walls, back, extremities), the outer and inner surfaces of the calvarium, the epidural and subdural surfaces of the intracranial and spinal dura mater, the eyes (including the optic nerves), and any subcutaneous and/or skeletal anomalies including suspected physical injury. Alternative light source photography may enhance the physical assessment of bruises.(32)

Radiography:

As per the NAME autopsy standards, a radiological skeletal survey is performed in the evaluation of these deaths.(25, 33, 34) Because acute and remote osseous anomalies and injuries can be missed during a routine autopsy, dedicated radiographs of the skeleton performed prior to autopsy may help to identify them.(25, 33) A second set of rib radiographs taken following the evisceration has been found useful by some to better visualize/document subtle fractures.(35) A pediatric skeletal survey is provided in Table 3. Due to limitations of body positioning, using this survey, rather than one ("babygram") or two radiographs, improves the ability to diagnose subtle fractures and bone diseases. Forensic pathology fellowships include training in examining postmortem radiographs, however, consultation with a radiologist who has experience with pediatric postmortem radiographs may be appropriate in some circumstances.

Advanced Radiologic Techniques:

Many infants and toddlers who present as a possible head trauma death will have been hospitalized prior to death, and many will have clinical radiographs, as well as computed tomography (CT) and magnetic resonance imaging (MRI) scans. Hospital radiological data can be reviewed in conjunction with postmortem CT (PMCT) data (if any), along with the autopsy findings to confirm or refute radiologic observations made prior to death, and to better understand the evolution of disease and injury.

Research has shown that PMCT has utility in supplementing traditional autopsy in certain types of adult and non-forensic fetal and pediatric deaths.(36-38) PMCT may add useful information to the detailed evaluation of a pediatric forensic death investigation. However, traditional (external and internal examination) autopsy is still the mainstay of pediatric forensic pathology.(39) High resolution data collected via PMCT also may be used to produce 3D images and specimens to further document injuries and disease. PMCT is not considered suitable for supplanting full-body radiographic studies as it lacks the sensitivity and specificity for detection of many metabolic bone diseases (that may predispose to fracture), minute injuries (e.g. classic metaphyseal lesions), and subclinical anomalies like subperiosteal new bone formation.(40-42) The diagnostic sensitivity increases when both are performed as the sensitivity of certain injuries is lower for PMCT than for plain radiographs.(43-45) Although concomitant use of PMCT scans and plain radiographs can be useful, only a minority of offices have CT scanners. Some forensic autopsy centers and offices have arranged access to CT scanners at local hospitals. The use of PMCT remains at the discretion of the forensic pathologist and subject to the availability of facilities and funding.(46) Protocols have been developed to provide optimal scan data in the postmortem setting (See Table 4).(40) Some forensic pathologists have training/working knowledge to examine postmortem CT scans. Consultation with a pediatric radiologist who has experience with PMCT may be appropriate in some circumstances.

Core Autopsy Steps

External and Internal Examination:

Depending on the age of the infant/young child, certain body measurements (e.g., head circumference) in addition to length and weight may be important. A search for trace evidence and sexual assault evidence collection, if indicated (as mentioned above), is performed prior to washing the body. An external and internal examination is performed per the NAME Forensic Autopsy Performance Standards which are also followed when describing an injury (e.g., type, location size, shape, pattern).(25) Per NAME standards, the forensic pathologist provides direct supervision of all technical processes and directly observes the removal of the skull cap and exposure of the brain to minimize the risk of misinterpreting artifactual hemorrhages as being of medicolegal relevance.(25)

Autopsy Considerations by Body Region:

As the autopsy progresses, the need for additional and/or more detailed examinations may be guided by findings relevant to the consideration of a diagnosis of inflicted head trauma.

<u>I. Head</u>:

Scalp and Face:

As per the NAME standards, the number, location, and size of hemorrhages of the external and undersurface of the scalp can be documented through a combination of photograph(s) and narrative description(s).(25) One is then able to correlate the sites of hemorrhage and medical intervention (e.g., surgery, intracranial pressure monitoring catheter, electroencephalogram leads) and other processes unrelated to direct impact, such as areas of bleeding along sutural diastasis secondary to cerebral edema. This documentation assists the reviewer of the autopsy report and photographs to distinguish primary (traumatic) injury from secondary findings (e.g., consequences of therapy, postmortem artifact, etc.).

If there is concern for facial injuries that are not apparent externally, or if further assessment of the extent of a known or apparent facial injury is needed, a formal face dissection can be performed that does not alter the appearance of the infant or child.(47) Advanced radiologic imaging also may be informative. The detection of otherwise unknown or underappreciated impact sites of the face may change the context of an infant death from one of non-impact to one with demonstrable impact. Intraoral examination may reveal frenulum, inner cheek, and tongue injuries. Shaving hair allows for better evaluation and documentation of scalp injuries. Careful examination of the ears includes looking inside and behind the ears. An otoscope permits examination of the ear canal and tympanic membrane allowing for detection of fluid, extravasated blood or tissue, or exudates. Dissection of the scalp is performed to expose as much of the underlying calvarium as possible, paying particular attention to anomalies and/or injuries suggested by radiological images obtained during life or pre-autopsy.

Skull:

Per the NAME autopsy standards, documentation of the location, dimension, type (e.g., linear, depressed, comminuted, diastatic) of fractures can be achieved through the narrative report, photography, and radiological imaging.(25, 48, 49) Some forensic pathologists supplement their reports with diagrams. In the absence of apparent calvarial fractures, pericranial membrane removal can discover subtle fractures (particularly those limited to the ectocranium, or those undergoing healing). The forensic pathologist is cautioned against reflexive stripping of the pericranial membrane in areas with obvious fractures as microscopic evaluation of known or suspected fractures is enhanced by evaluation of these tissues with respect to their anatomic location and relationship with the injured bone. The skull is opened using an oscillating saw as routine. Pathologists are cautioned against "flower petal" exposure of the brain opening along suture lines as this may cause disruption of the dura mater and its sinuses (see Meninges, below) and may interfere with the assessment of diastatic fractures. During fellowship, forensic pathologists receive training to evaluate skeletal trauma; consultation with a board-certified forensic anthropologist may be appropriate in some instances.(35-37, 50, 51)

Both the calvarial and basilar dura mater are removed from the skull, and the exposed skull surfaces are photographed. High resolution radiographic techniques (e.g., pathology specimen radiology imaging system) are used by some to further clarify the nature of suspected fractures prior to microscopic studies. Portions of apparently fractured skull and contralateral apparently unfractured ("normal") skull tissue may be retained for microscopic evaluation. In rare circumstances it may be appropriate to retain the entire calvarium.

Meninges:

Examination of the cerebral dura is an important component of the autopsy. This includes describing the surfaces, the dural venous sinuses, and any corresponding pathology (e.g., pus, hemorrhage, surgical defects, thromboses of the sinuses or bridging or cortical veins, etc.). Dural venous thrombosis is important to document and may be missed without careful examination.(52-58) The types of hemorrhage include epidural (EDH), subdural (SDH), and subarachnoid (SAH). Their location (e.g., convexity, base, interhemispheric, posterior fossa, etc.), distribution (e.g., patchy, diffuse), size, color, and adherence to the dura can be documented through appropriate use of narrative descriptions and photography. The sizes of

SDHs and EDHs can be documented by volume, weight, or 3-dimensional measurements (length, width, and thickness). The effects of any hemorrhage on the brain (e.g., compression, herniation, shift) are recorded.

For any known or suspected head trauma cases, retention of the dura for further gross and microscopic examination is recommended by various studies and experts.(56, 59, 60) Although it is not always possible, it can be helpful for later examination to strip the cranial dura as one piece, with sinuses intact, to preserve as much orientation as possible. For later orientation, the dural arteries are on the epidural side and the middle meningeal artery is directed posteriorly. If this is not possible, the dural strips need to be oriented. The dura can be preserved as a flat piece with a method that minimizes curling and wrinkling during fixation. This can be accomplished by using traditional surgical pathology techniques such as pinning the dura mater flat against paraffin wax sheets/cork board or between two flat objects (like two stock jar lids) and then submerging it in formalin. If consultation with a neuropathologist is sought, the forensic pathologist documents and conveys findings apparent at autopsy such as liquid and non-adherent blood that may be dissolved or dislodged during fixation. To that end, the forensic pathologist also shares investigative information, medical data, autopsy findings (including photographs), clinical radiographic findings, and PMCT images, etc., as this information provides the neuropathologist with comprehensive information necessary to correlate observations and form well-informed diagnoses.

Microscopic sections of the dura help confirm and document gross findings and provide additional data that may be useful to assess the stage of healing.(61-64) Microscopic examination of the dural sinus may help distinguish thrombus from postmortem congealed blood. Intradural hemorrhage also may be seen, especially in sections around the dural sinuses. Representative sections of the dura can be taken for histology either before fixation, after fixation, or a combination thereof depending on the findings. SDH and EDH sampling from central and peripheral areas and from areas of differing appearances can be helpful in further evaluation of the hemorrhages. For comparison to published descriptions of the temporal sequence of SDH healing, it is helpful for the report of microscopic findings to describe the cellular composition and organization.(62-65) Many variables affect the process of SDH/EDH healing (e.g., size of hematoma, source of blood, age, and health of the individual) resulting in a somewhat predictable but variable course.(61) It is important to recognize that macrophages and iron deposits can be detected in the dura of infants and children without concurrent acute intracranial hemorrhages as the consequence of birth-related subdural hemorrhages.(66) Evaluation and demonstration of the evolving maturity of dural or leptomeningeal hemorrhages may be aided with the use of special stains and immunohistochemical techniques.(64)

Brain:

Neuropathologists recommend that the pediatric brain is formalin-fixed prior to dissection which allows for thinner cut sections and better anatomical preservation given the incomplete myelination of pediatric brains.(24, 67, 68) Although many different techniques exist to facilitate preservation (67), most forensic pathologists will choose to fix the neurological tissues and dura mater in 10% or 20% formalin for 10-14 days prior to dissection. The brain is freely suspended in an adequate volume of formalin via the basilar artery or other vessels at the base. Another approach is to add sodium chloride to the formalin which will allow the brain to float. Suspension of the brain within a bonnet or other autopsy material may introduce artifacts (e.g., flattening of the cortical surface). Prior to evaluation of the preserved brain, it may be useful for the forensic pathologist to review antemortem (particularly admission) CT and MRI scan data that may document intracranial hemorrhage, effacement of subarachnoid cisterns, hypoxic-ischemic injury, and vascular thromboses.

Forensic pathologists are trained to diagnose and describe a broad spectrum of neuropathologic entities including disease and physical trauma. The approach to the forensic neuropathologic evaluation of the brain is to evaluate for disease and injury.(60) As some diseases may be subtle or mimic trauma, consultation with a board-certified neuropathologist who has forensic experience may be warranted, before or after dissection of the brain.(60) Retention of representative cortical regions, deep gray structures, brainstem, and cerebellum is usually sufficient.(60, 69)

Microscopic sections for suspected inflicted traumatic brain injury include evaluation of grossly identified pathology and sampling that allows for the assessment of a broad spectrum of neuropathologic findings including disease processes, hypoxic-ischemic brain changes, and axonopathy (including, when possible, that which is traumatic in origin).(60) Hypoxic-ischemic brain changes in infants/children have a characteristic geographic distribution, and those regions are included in the evaluation in addition to regions typically involved in adults.(60, 69, 70) A list of locations for histologic sampling for hypoxic-ischemic brain injury is in Table 5. Diagnosis of diffuse traumatic axonal injury (dTAI) requires traumatic axonal injury in multiple locations including the corpus callosum, cerebral hemispheric white matter, and brainstem, distinct from the axonal changes typical of ischemia.(71-74) Histological sampling for dTAI in infants and children includes routine H&E sections. If available, examination with amyloid precursor protein (APP) immunostaining may be useful in select instances.(74-76) A list of locations for histologic sampling for dTAI is included in Table 6. Limited sampling has been demonstrated to preclude the diagnosis of dTAI; therefore, if traumatic axonal injury is present but insufficient to diagnose dTAI, additional (bilateral) histological sections are evaluated. Assessment of APP immunostaining patterns due to trauma and a variety of other processes have previously been reported, as well as caveats associated with the analysis.(72, 74, 76-78) If special or immunohistochemical stains are needed in offices which do not have these services in-house, these services are available through commercial pathology laboratories and academic centers. It should be noted that the commercially available APP immunostains have minute differences in antibody, clone, antigen retrieval techniques, and even the counterstain can alter the detection and interpretation of findings. Many experts recommend microscopic evaluation for disease processes to include examination of neocortex, deep gray structures, brainstem, and cerebellum. Histological sampling and use of special stains, however, may vary depending upon the clinical history and gross pathology at autopsy. Marked non-perfused brain changes (so-called "respirator brains"), for example, may dramatically impact brain integrity, and thus the process of dissection and sampling. However, careful evaluation of the brain is still possible, and may prove highly valuable particularly through microscopic analysis.

The Eyes:

Much has been written about the documentation and location of hemorrhages and/or hemosiderin in the eyes of suspected pediatric head injury.(79-84) As vitreous fluid collection may create artifacts and thus disturb the ocular anatomy, the forensic pathologist will need to make a case-by-case decision about the necessity for eye dissection versus the probative value of vitreous humor collection for toxicological/chemical testing. Non-invasive techniques can be used to assess ocular pathology at autopsy. Monocular indirect ophthalmoscopy is a non-invasive and non-destructive technique to view the retina prior to autopsy.(85, 86) This technique may assist in deciding between different ancillary studies (i.e., microscopic evaluation of the retina versus collection of vitreous humor for toxicological/chemical testing). Detailed descriptions of the techniques for removing the eyes at the time of autopsy have previously been published.(87-89)

After removal, the eyes, optic nerves, and attached soft tissues can be photographed both fresh and after fixed intact in formalin (ideally for at least 48 hours). There are described techniques for sectioning the globe, however a single pupil-optic nerve section, made with as sharp a blade and as smooth a cut as possible, and without additional sectioning to create "calottes" will minimize disruption of the intraocular contents. (87) If, however, a concerning lesion is seen focally within the apex of one of the bisected segments, a calotte section may be advisable to best capture this finding histologically.

A gross description at the initial examination can document both intraocular and extraocular hemorrhage, retinal detachment or retinoschisis, pathological retinal folds, and optic nerve edema. Common semi-quantitative descriptors of retinal hemorrhages are: none, a few, numerous, or too numerous to count. The distribution within the globe from posterior to periphery (ora serrata) can be documented in several ways. One option is to draw the findings on a fundal diagram. The bisected globe sections can also be photographed. The literature and other pathologists or agencies can assist on how to produce reviewable, high-quality photographs.(90, 91) Photography under a dissecting microscope provides detailed, high-magnification images; however, if a dissecting microscope is not available, a camera with an appropriate zoom lens may be used. If necessary, glare in the photograph can be reduced by immersing the bisected globe in 60 or 70% ethanol, or in normal saline if ethanol is unavailable. Absent such resources, a bright flashlight held at various angles can aid in the documentation of ocular findings. The use of diffused or polarized light can help to minimize reflections and enhance contrast. Due to the lack of contrast between dark hemorrhages and surrounding dark retina, and the difficulty of photographing into the concavity of an eye, ocular transillumination has been studied and shown to yield high contrast images of retinal findings.(91)

To minimize compression artifacts, the bisected globe sections can be submitted in two separate deep (at least ½ inch) cassettes for processing. To examine a greater surface area of the retina, multiple hematoxylin and eosin-stained (H&E) upfront levels can be ordered. Many different special stains and immunostains have been studied for complementary use during postmortem eye examinations(92); H&E stains remain the mainstay of evaluation. A Prussian blue stain (iron) can be used for the detection of hemosiderin in appropriate circumstances.(93, 94) Microscopic findings such as hemorrhage and/or hemosiderin (subdural, subarachnoid, orbital fat, scleral, retinal, vitreous) along with any other ocular pathology is included in a written report.(25) Other pathology descriptions such as which retinal layers are involved (sub-internal limiting membrane, nerve fiber/ganglion cell layer, inner nuclear/inner plexiform layer, outer nuclear/outer plexiform layer, and subretinal), the locations of any pathology in the eye (e.g., posterior pole, mid periphery, far periphery), and the extent of the hemorrhages also is included in the written report. Though such descriptors are by nature qualitative, examples include: focal for an isolated hemorrhage, multifocal for multiple discrete hemorrhages, and extensive for hemorrhage that has become confluent.

II. Neck, Spine, and Ribs:

Infants and children who die of inflicted injuries may have injuries of their anterior and posterior necks. Certain types of injury mechanisms have been associated with physical injuries of connective tissue, chrondro-osseous, and neural structures of the cervical spine. These injuries of the neck have been proposed to explain potential mechanisms of death. For these reasons, techniques have been described for the examination of the anterior and posterior neck and intrinsic spine structures/nerve roots.(60, 71, 95-102)

As injury may involve different areas of the spinal cord in suspected pediatric head trauma deaths, it has been recommended that the entire length of the spinal cord (and its coverings) be examined.(60, 101, 102) Regardless of the approach taken to dissect the spinal cord, the forensic pathologist evaluates the relationships between the spinal cord, proximal nerve roots, dura, and overlying soft tissue and chondro-osseous structures. Following evisceration and neck dissections, the spinal cord can be approached via routine anterior or posterior techniques. The method of spinal cord removal depends upon historical, investigative, imaging, and/or autopsy findings that indicate forces may have been applied to the torso. Specialized options are available for the vertebral column when there are suspected flexion/extension injuries or rib or vertebral fractures:

Special Spinal Cord assessment when there are Suspected Flexion/Extension Injuries:

If the prosector is concerned for intrinsic structural spinal/nerve root injury, there are a variety of techniques to facilitate these dissections.(101-103) One method is an en-bloc dissection of the cervical osseous and neural structures with formalin fixation.(103) This technique may help to address any antemortem MRI suggestions of cervical spine trauma (e.g. nuchal and interspinous ligament edema and lacerations, chrondro-osseous and joint space disruptions, etc.) along with the anatomy of the cervical spinal cord and nerves (along the post-ganglionic length of the nerve).

Another technique is an in-situ method that removes the spinal cord and attached ganglia without the surrounding bone and soft tissues.(102) Here, the laminae are cut and removed exposing the spinal cord in situ. Then the lateral aspects of the neural arches are removed by cutting the articulating facets and pedicles of the vertebrae. The freed sections of bone are removed exposing the ganglia in-situ. Once the spinal cord and attached ganglia are exposed, they can be removed as a single block of tissue allowing the position of each ganglion to be maintained. In situ approach to the dissection of the cervical spine does disrupt the soft tissue and chrondro-osseous structures which may alter or prevent evaluation of hemorrhages along or within the minute nerve structures. Histological evaluation of the spinal cord (and its coverings) may demonstrate microscopic hemorrhage or injury.

Special Spinal Assessment for Vertebral and Rib Fractures

Following evisceration, anterior and posterior neck dissections, and back dissection, the cervical, thoracic, and lumbar portions of the spine can be freed from the body and removed in continuity with the proximal segments of each rib. Following formalin fixation, any of a variety of decalcified or non-decalcified specimen approaches can assess the entire length of the spinal cord and its relationship to overlying/adjacent chondro-osseous and soft tissue structures.
For rib fractures, the spine can be freed from the body and removed in continuity with the rib cage. Rib fractures (including apparent rib fractures) and normal (“control”) contralateral ribs can be sampled histologically using a variety of standard techniques.

III. Trunk and Upper and Lower Extremities:

The NAME autopsy performance standards include procedures and descriptions for trunk injuries. A subcutaneous examination of the arms, legs, back, and buttocks may improve detection of occult subcutaneous and deep soft tissue hemorrhage.(104) If metabolic bone disease is a reasonable consideration, portions of iliac crest, costochondral junction, or lumbar spine can be preserved in 40% ethanol for possible undecalcified bone histology assessment.(105, 106)

Of particular importance are the identification and description of rib (see above) and other skeletal fractures. In addition to radiographs, an in-situ skeletal examination may further document or exclude injury. An in-situ examination may include exposure of the shaft and epiphyseal cartilages of the ribs, clavicles, long bones, vertebrae, and scapulae.(49) Traumatized or abnormal structures can be removed for additional analysis including radiology and gross dissection with histological examination.(107-109) When possible, a description of the stage of healing (i.e., bone callus formation) is included in the autopsy report. The contralateral (i.e., "normal") bone can be used for "control" purposes, and to better understand the infant/toddler's underlying normal bone physiology/anatomy. Because some osseous findings may be unusual normal anatomic variants mimicking trauma, consultation with a board-certified forensic anthropologist or pediatric radiologist may be useful. Rib fractures caused by attempts at cardiopulmonary resuscitation have been described in the pediatric population.(110-112) Other useful techniques and examinations include stripping the parietal pleural lining to identify subtle rib fractures and taking histologic sections of cutaneous/subcutaneous injuries (Prussian blue stain can identify microscopic hemosiderin).

Examination of the internal organs

Standardized approaches to the examination and dissection of the internal organs have been reported elsewhere and are discussed in the NAME autopsy performance standards.(2, 25) Of particular relevance is a detailed evaluation of the heart and lungs. As pulmonary pathology is a frequent complication of critical care therapy, and because pediatric lungs are particularly prone to collapse at autopsy (which subsequently imparts the false impression of hypercellularity, and therefore may complicate the evaluation for antecedent infectious states), pathologists may consider formalin perfusion of the lungs (or heart-lung block) prior to examination and histologic sampling.

IV. Ancillary studies:

Depending upon the circumstances and autopsy findings, ancillary studies for infectious (e.g., viral, bacterial cultures), hereditary, metabolic, or thrombophilic diseases may be indicated. Blood collected in a lavender top tube, which contains ethylenediaminetetraacetic acid (EDTA), is an appropriate specimen for genetic/molecular testing if needed. If blood cannot be obtained, other tissues (e.g., heart, liver, spleen, skin) can be used for testing, so long as appropriate methodologies for storage and preservation are used (e.g., an ultra-low temperature freezer, Roswell Park Memorial Institute (RPMI) medium used for cell culture, glutaraldehyde, RNAlater, etc.). A wide variety of molecular and genetic tests are available including whole genome/exome analysis and targeted studies for cardiomyopathies, channelopathies, thrombophilias, and bone weakening conditions. The ability to test for these disorders may be lost without appropriate foresight. As such, it is useful for forensic pathologists and their agencies to consider the pre-emptive development of specimen retention and storage plans that facilitate later unanticipated testing.(113)

V. Medical Records:

Review of medical records, including antemortem CT/MRI reports, may provide relevant clinical information and reveal issues that may be resolved during the postmortem examination. Neurologic status at presentation, the clinician's initial observations of any injuries, radiographical evidence of intracranial findings (e.g., mass effect, swollen brain), intra-operative observations, ophthalmologic consultation findings, cerebral perfusion studies, venous sinus thrombosis studies, antemortem coagulopathy testing, etc., may provide additional useful information. Additionally, antemortem pediatric medical records, if available, may provide a more inclusive picture of the child's overall health and pertinent family medical history.

VI. Other Records and Circumstances:

Many pediatric death investigations involve several agencies who conduct collaborative parallel investigations to determine what happened to the child. The forensic pathologist's focus is on cause and manner of death determination and if there is injury, how it occurred. Circumstances will differ from one death to another and as such, there may be a need to review information gathered by other agencies concerned with child welfare, such as child protective services and law enforcement. Depending on the jurisdiction, child abuse protocols may exist, and these may help identify agencies and contacts who may be able to provide preliminary investigative information or indicate whether the child or family had prior contact with law enforcement or child protection agencies.

This exchange of information is mutually beneficial, as the forensic pathologist may be able to identify instances in which the physical findings at autopsy are either consistent or inconsistent with the given version(s) of events. As with any medical specialty, historical and circumstantial information is critical in the development of a cogent differential diagnosis, and its use should not be conflated with contextual bias.(114)

VII. Organ and Tissue Donation:

Organ and tissue donation is possible in pediatric homicides in which the child has been hospitalized.(115) Forensic pathologists balance their willingness to facilitate donation against their mandate to advocate for the truth and provide transparency in each case.(116) In some jurisdictions, a forensic pathologist may attend the donation procedure to document injuries and other pertinent findings subject to potential alteration. Before considering donation restrictions, the forensic pathologist considers the available medical records and preliminary information generated by any parallel investigations. For heart valve donation, the forensic pathologist may receive a cardiac pathology report or the option of examining the remaining heart tissue.(117, 118)

Organ procurement organizations and local medical examiners/coroners are encouraged to establish a professional relationship that includes generating and adhering to agreed-upon protocols. Medical examiners/coroners use investigative information to weigh their investigative duties and responsibilities with the family's desire to donate.(115)

Conclusion

The investigative value of each of the described studies is often unknown at the onset of the autopsy. Many procedures performed during an autopsy create irreversible changes to tissues and thus proactive documentation is critical. Ultimately, the forensic pathologist uses medical judgment on how to conduct each autopsy examination.

Table 1. Broad recommendations specific to the suspected pediatric head injury autopsy

1. Full body external photographs with close-ups of specific findings and pertinent negative findings
2. A radiological skeletal survey (not a so-called babygram)
3. PMCT findings reported within or accompanying the final autopsy report (when available)
4. Documentation of the scalp and intracranial hemorrhages
5. Documentation of the formalin-fixed brain, dura mater, and spinal cord (with the ability to consult with a board-certified neuropathologist if deemed necessary)
6. Documentation of the eyes, optic nerves, and ocular soft tissues (with the ability to consult with an ocular pathologist or board-certified neuropathologist if deemed necessary)
7. Evaluation of the anterior neck, posterior neck, back, and extremities
8. Consider evaluation of the intrinsic anatomy of the cervical spine (nerve roots, chondro-osseous structures)
9. Documentation of abnormal bone structures including suspected and diagnosed fractures
10. Review of medical records for correlation with the history and autopsy findings
11. Review of investigative circumstances and consider directly visiting the scene and/or performing a re-enactment

Table 2. Photographs

1. As-is photographs of the anterior and posterior body upon opening of the transport bag, and prior to removing medical devices and cleaning
2. Clean photographs of the:
    a. Face (“identification” photograph)
    b. Anterior, posterior, right, and left views of the head and face
    c. Extended anterior neck
    d. Chest, abdomen, and back
    e. Genitals and perianal region
        i. Ventral and dorsal penis and the undersurface of the scrotum
        ii. Open and closed vulvar labia
    f. Arms and legs including wrists, ankles, and hands
    g. Soft tissue plane dissections (e.g., torso, back, extremities, anterior and posterior neck)
    h. Anterior, posterior, right, and left views of the surface of the reflected scalp and exposed pericranial surfaces
    i. Exposed cranial surfaces following pericranial membrane and dura removal
    j. Epidural, subdural, and subarachnoid compartments at autopsy
    k. At least an as-is photograph of the brain inside the skull
3. Formalin-fixed photographs of:
    a. The brain and spinal cord (overall and cut sections)
    b. Cervical spine and/or cervical nerve roots as indicated
    c. The eyes and optic nerves (overall and cut sections)

d. External and cut surfaces of retained osseous structures and internal organs (e.g., heart/lungs) as indicated

*A case number should be visible in each photograph with a reference scale for major wounds.(22)

Table 3. Pediatric radiologic skeletal survey

1. Three views of the skull
    a. Anterior-Posterior (AP)
    b. Towne's (30% angle view of the mandibular condyles and the midfacial skeleton)
    c. Lateral

2. Two views of the cervical spine
    a. AP
    b. Lateral

3. Two views of the trunk / torso
    a. AP
    b. Lateral

4. Two views of the ribs
    a. Left posterior oblique (LPO)
    b. Right posterior oblique (RPO)

5. Four views of the upper extremities
    a. Left and right upper extremity
    (isolated view of humerus may be useful)
    b. Left and right hand

6. Four views of the lower extremities
    a. Left and right lower extremity
    (isolated view of femur may be useful)
    b. Left and right foot

Table 4. Postmortem Pediatric CT-Scan Protocol

1. Whole body scan (vertex through extremities)

2. 120 kVp

3. 200 mAs

4. Pitch 0.5 to 0.8

5. Slice thickness 0.5 mm

6. Energy – single source

7. Dose modulation off

8. Adjust SFOV to patient size (small as possible)

9. Detector collimator 0.5 mm

10. Rotation time 1 s

11. Matrix 512 x 512

12. Kernel / filter / algorithm:

    a. Soft tissue and bone (whole body)

    b. Head (to include mandible)

    c. Brain (brain coverage)

    d. Lung (thoracic coverage)

13. Reformats:

    a. Coronal

    b. Sagittal

    c. Volume rendering

Table 5. Histological sampling of the brain for hypoxic-ischemic brain injury.

1. Watershed/border zone cortex (e.g., frontoparietal region)
2. Deep gray structures (basal ganglia/thalamus)
3. Hippocampi (including subiculum)
4. Midbrain (inferior colliculus)
5. Pons
6. Cerebellum

Table 6. Histological sampling of brain for diffuse traumatic axonal injury (dTAI).

1. Splenium of corpus callosum
2. Bilateral parasagittal white matter
3. Posterior limb of the internal capsule
4. Midbrain (decussation of superior cerebellar peduncle)
5. Pons (middle cerebellar peduncle)
6. Medulla (pyramids)

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