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Abstract

Injury, both intentional and accidental, is the most common cause of death in children throughout the world. Many injury patterns that are seen in children are similar to those in adult populations; however, others differ, reflecting the age, stature, and development of children. This chapter focuses on differences in injury patterns of children across the spectrum of childhood development and growth, including injuries and fatalities that primarily occur in infancy and early childhood. Risk factors for injury and death are identified within the context of childhood development. Topics covered include deaths associated with motorized and nonmotorized vehicles including pedestrian, occupant, and operator fatalities; farming and ranching deaths; drowning, boating, and diving deaths; fires and burns, including electrical deaths; animal-related deaths; falls; and airway-associated deaths. There are significant disparities in childhood injury and death among racial, ethnic, geographic, and socio-economic groups. A brief consideration of these differences is provided to assist in forensic case examination.

Introduction

Accidental injuries cause a high proportion of deaths in children. In some age groups, injury is the leading cause of childhood death. Injuries and death differ across the spectrum of childhood development and growth (Agran et al. 2001, 2003). An understanding of these differences is critical to the performance of a forensic investigation and autopsy in children and adolescents; conversely,

well-performed forensic investigations and autopsies will identify risk factors and opportunities to reduce childhood morbidity and mortality from injuries.

Vehicle-Related Deaths

Pediatric vehicle-related injuries and deaths are commonly seen in forensic pathology. Infants and children may be occupants in motor vehicles or may be pedestrians struck by motor vehicles. Children may be operators of recreational vehicles, including bicycles, and in adolescence, drivers of motorized vehicles. Worldwide, over 260,000 children die annually in road-related crashes, and children accounted for 21 % of all road fatalities (World Health Organization 2012b). Childhood deaths from vehicle-related events are highest in Africa and are consistently increased in low- and middle-income countries as compared to higher-income countries throughout the world (World Health Organization 2004).

Passenger Injuries

Each year in the United States (USA), about 1,400 children under the age of 14 years are fatally injured while passengers in motor vehicles, and another 200,000 sustain injuries, many of which significantly impair the child's quality of life (Department of Transportation (US), National Highway Traffic Safety Administration (NHTSA) 2009). The Centers for Disease Control and Prevention (CDC) in the USA estimates that restraint systems for children (positioning, age, and weight-appropriate car or booster seats, lap and shoulder harnesses, etc.) prevent 400–500 fatalities each year (Centers for Disease Control and Prevention 2012e). These same initiatives also reduce childhood fatalities in other regions of the world. However, restraint systems may also cause injury and death, particularly when improperly used for the age, size, and development of the child, or when a child is seated in the front seat of a vehicle. The American Academy of Pediatrics and the CDC have each produced guidelines and best practices for child passenger safety (Centers for Disease Control and Prevention 2012e; American Academy of Pediatrics Committee on Injury, Violence and Poison Prevention 2011). Children under the age of 13 years should always ride in the rear seats of vehicles. As a general guideline, rear-facing car seats should be used until the age of 2 years. After 2 years of age, forward-facing child seats should be used until the child is over 4 years of age or 40 lb (18 kg). Belt-positioning booster seats should be used after that point until adult lap-shoulder seat belts fit appropriately at upper thighs and chest when a child is over 8 years of age and 4'9" (1.4 m) tall. Disabled children have a similar incidence and distribution of injuries related to safety restraint use as compared to children without disabilities (Huang et al. 2009).

Head Injuries

A review of forensic findings from passenger airbag injuries demonstrates that face, upper extremity, and chest injuries are more common in children than adults,

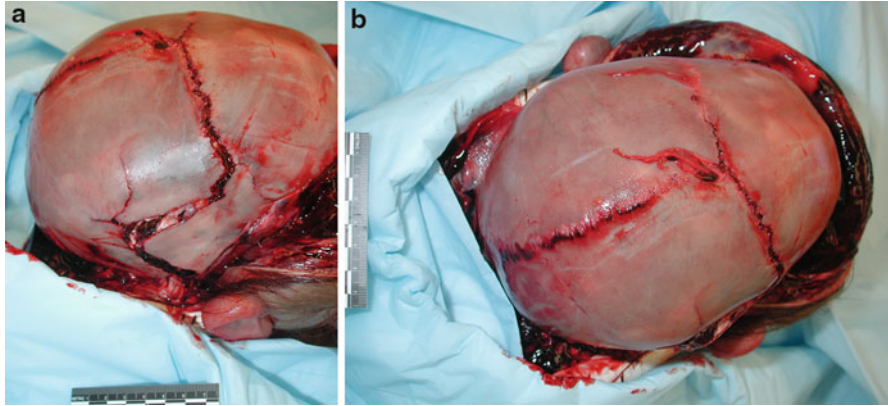


Fig. 27.1 Airbag head injury in an infant riding in the front seat of a car. (a) Skull fracture from a deployed airbag in a 6-month-old infant. The infant was in an unsecured infant seat located in the front seat of a car. (b) Separation of sutures and extensive galeal hemorrhage are present

and isolated head injuries are more common in infants as compared to older children (Sato et al. 2002). In the majority of airbag injuries, a child was unrestrained or improperly restrained in the front seat, and all injured infants were in the front seat in rear-facing child restraint seats (Fig. 27.1a, b). The smaller stature of children and infants and the position of the head closer to the upward deploying airbag may account for the mechanism of these injuries. The relatively flat and horizontal character of the atlanto-occipital (AO) articulation in children also places them at greater risk of AO dislocation or separation (Saveika and Thorogood 2006). Other large studies have confirmed passenger airbag injuries when children under 14 years of age occupy the front passenger seat (Newgard and Lewis 2005).

Head injuries occur in children restrained with adult seat belts (Fig. 27.2a, b). An adult-designed shoulder harness may cross the child's face and/or neck. Children may slip the belt under an arm or behind the back, compromising the restraint of the upper torso making these areas susceptible to injury in a collision with rapid deceleration. In a crash, the unrestrained forward motion of the child's upper body may cause the head to collide with knees or parts of the vehicle. Small children may also "submarine" completely out of an adult restraint system on impact, become airborne, collide with the interior of the vehicle and/or other occupants, or may be ejected from the vehicle (Tibbs et al. 1998).

Abdominal Injuries

Children are more vulnerable to blunt abdominal injury from vehicular seat-belt restraints as compared to adults, particularly when child booster seats are not used or the child is inappropriately restrained by the lap-shoulder harness system designed for adults (Lapner et al. 2001). Current recommendations call for use of special child restraint systems until the child is over 4'9" (1.4 M) tall, and the lap restraint can be positioned on the upper thighs (not the abdomen) and the



Fig. 27.2 Injury caused by an adult shoulder harness restraint in a child. (a) The 12-year-old boy was slight in stature at 55 in. (1.4 M), below the recommended height for adult seat belt use. Injury pattern demonstrates the restraint position was across the neck and face instead of the intended design of across the chest. (b) A basilar skull fracture was present and the head injury caused the death of this child

shoulder harness crosses the chest while not crossing directly over the neck (American Academy of Pediatrics Committee on Injury, Violence and Poison Prevention 2011). The immature pelvis of a child under the 4'9" (1.4 M) height requirement cannot be appropriately restrained with the lap-shoulder harness until the child is tall enough to position the harness in the correct areas (across the thighs and not the abdomen). Abdominal-wall contusions are infrequent in both optimally and suboptimally seat belt-restrained children, but when abdominal contusions are present, they often herald intra-abdominal injury (Lutz et al. 2004). Intestinal injury, perforation, and shearing of the fixed ligaments and mesenteric structures are the most common abdominal manifestations of pediatric seat belt-related injuries (Davies 2004). Because the small anterior pelvis of a child is not appropriately stabilized by the lap restraint system designed for adults, deceleration allows the seat belt to override the child's pelvis, producing hyperflexion of the child over the lap belt. This forces the abdominal organs against the vertebral column and momentarily increases the intraluminal pressure of the hollow organs, resulting in sudden compression. In addition to the abdominal injuries, the deceleration-induced compression and hyperflexion of the abdomen may also cause lumbar spine and sacral injuries (Hart et al. 2004; Papavasiliou et al. 2007). Intestinal compromise may be immediate or may occur days to weeks after the injury (Hardacre et al. 1990; Lynch et al. 1996).

Posttraumatic small-intestinal obstruction and delayed perforation may comprise an important finding in a forensic evaluation of a delayed vehicular death.

Pedestrian Injuries

Pedestrian deaths in children demonstrate age differences in the types and patterns of injury. In children under the age of 4 years, deaths from “backover” accidents in driveways peak in incidence, likely due to the small stature of children, their tendency to “hide” or play behind parked vehicles, and their lack of awareness of the dangers of moving vehicles. Crush injuries of young children, usually occurring from low-velocity impacts resulting from vehicles backing out of home driveways, are often fatal due to blunt-force injuries of the head (including closed-head injuries), skeleton, and torso (Partrick et al. 1998). The most common vehicles involved in these accidents are sport utility vehicles (SUV), trucks, and minivans, as opposed to passenger cars (sedans, compact cars, etc.), perhaps due to the increased frequency of larger vehicle ownership by families with small children and the increased “blind spot” of vehicles with higher ground clearance behind the vehicle. In contrast to most other vehicular head injuries, these “backover” injuries are generally static; that is, they do not have significant rotational and acceleration–deceleration components.

Pedestrian injuries of older children tend to be on roadways rather than home driveways. This reflects cognitive awareness of the age groups: younger children are more at risk of mid-road impacts, associated with impulsive behaviors, such as darting into traffic in areas other than crosswalks; older children and adolescents are more likely to be involved in pedestrian accidents at crosswalks and intersections. As compared to head injuries sustained in “backover” collisions, head injuries in pedestrian roadway accidents in older children and adolescents tend to be complicated by rotational and acceleration–deceleration components as opposed to isolated static forces.

The site and character of pediatric pedestrian injuries also reflects the child’s age and development (Chakravarthy et al. 2007). The point of vehicular impact (bumper) in a small child is at the head or chest level, both sites that are above the child’s center of gravity. Because of this injury location, the initial impact usually results in a second impact, with the initial impact projecting the child away from the vehicle and against another fixed object, usually the ground. Consequently, the child may be run over by a subsequent vehicle. In contrast, the impact point in older children is below the child’s center of gravity, resulting in impact patterns similar to that of adults. In older children, the impact point is at the legs with the body projected over or onto the hood of the car. Rotational motion is seen in these impacts with the legs rotating over the head on impact and with increasing speed, and the entire body may somersault over the vehicle following hood/windshield impact. The injury patterns seen in children reflect these different impact patterns, with head, neck, and chest injuries more common in pediatric pedestrian injury populations than in the adult population (Chakravarthy et al. 2007).

Pedestrian accidental deaths are more common in males and in children from minority groups, particularly in lower socioeconomic areas (American Academy of Pediatrics Committee Injury, Violence, and Poison Prevention 2009). This may relate to socioeconomic considerations including denser traffic patterns, increased vehicular speed, on-street parking, fewer guard-monitored crosswalks near schools or playgrounds, poor sidewalk maintenance, increased need for pedestrian transportation within lower socioeconomic communities, and reduced safety awareness (Hotz et al. 2009). Gender differences, as well as the potential influence on parental supervision, have been examined in the context of improving pedestrian safety (Barton and Schwebel 2007). Geographic information system (GIS) studies have assisted in targeting high-risk areas and led to a reduction in both injuries and fatalities (Weiner and Tepas 2009; Statter et al. 2011).

Operator Injuries

Children may be drivers/operators of a variety of nonmotorized vehicles (wagons, bicycles, gravity go-carts) or “off-road” non licensed motorized vehicles (golf carts, all-terrain vehicles, snowmobiles, motorized go-carts). Accidents from these vehicles cause a disproportionate incidence of injury in children when compared to adult populations (Siman-Tov et al. 2012; Lord et al. 2010; Hamming and Henry 2009; Curran and O’Leary 2008; Kelleher et al. 2005; DeCou et al. 2003; Rice et al. 2000).

Bicycles

Children operating bicycles may be injured from falls, collisions with objects, or collisions with other vehicles, including motorized vehicles. Head injuries, including traumatic brain injury, are the most common cause of fatalities involving bicycles; however, blunt-traumatic injury to abdominal organs, abdominal-wall injury, and genital injuries may occur, usually from impact with handlebars or bicycle frame (De Jong et al. 2011; Klin et al. 2011; Rowell and Chin 2011; Widni et al. 2011; Nellensteijn et al. 2009). Helmet use reduces the occurrence and severity of head injuries in bicycles and other motorized and nonmotorized vehicle accidents. (Barnes et al. 2012; Juang et al. 2010; Pardi et al. 2007). Some trauma centers report an increase in severe thoracic and abdominal injuries from bicycle accidents in children as helmet use increases, reducing the incidence of severe head injuries. (Klin et al. 2009). A 1995 review of 2,333 bicycle-related injuries in the National Pediatric Trauma Registry (USA) further identified children with mental disorders as a high-risk group for bicycle injury and suggested targeted prevention programs (Li et al. 1995).

Off-Road and All-Terrain Vehicles

Training and licensing prior to the operation of off-road and all-terrain vehicles is not as regulated, or as common, as licensed road vehicles (Upperman et al. 2003). The vehicles are often operated off-road and on irregular terrains, which contribute to vehicle instability and subsequent vehicle rollovers (Finn and MacDonald 2010).

Crush injuries and asphyxia may result from rollovers of heavy off-road vehicles onto individuals. Blunt trauma, fractures, and amputations may occur from impacts with trees, fences, or other obstacles. “Clothesline” injuries, including deep lacerations or cervical fracture, may occur to the face and neck when vehicles pass under horizontally strung fence lines. In some instances, multiple children are involved in an accident when an off-road vehicle is being driven with children riding on sleds or skateboards tied behind the vehicle (similar to waterskiing). If the vehicle makes a sudden turn, the increased rotational velocity may throw the child who is on the skateboard/sled away from the vehicle, resulting in blunt-force injuries due to the primary impact and/or a secondary impact with a subsequent structure (tree, vehicle, etc.). The majority of these accidents occur at lower velocities than traditional motor vehicle accidents, although some motorized off-road vehicles can reach speeds of 30 mph (50 km/h) or more, increasing the likelihood of fatal injuries and approaching patterns seen in traditional motor vehicle collisions.

Licensed Motor Vehicles

Adolescent drivers of licensed motor vehicles have higher accident and death rates as compared to adults. Injury patterns are similar, since adult size and stature are generally reached by the age of legal vehicular licensing. Many provinces, states, and countries have limited the adolescent (14–18 years of age) motor vehicle licensing in several manners, including increasing the minimum driving age, mandating driving courses, restricting hours of driving, limiting the number of adolescents in a vehicle, or requiring a licensed adult driver in the car (Russell et al. 2011). These and other regulations reflect efforts to reduce accidents and fatalities among adolescents until driving skills become more accomplished. Some jurisdictions may also limit or have additional requirements before licensing adolescents to operate motorcycles or may restrict operators less than 18 years of age to a smaller-sized motorcycle. On private property and some Indian reservations, state or provincial driving laws may not be applicable or enforceable, and children may drive motorized vehicles at a younger age.

Other Vehicular Injuries

There are some unusual vehicle injury mechanisms that forensic pathologists need to consider in pediatric death investigations. Infants are more susceptible to carbon monoxide toxicity due to the greater affinity of fetal hemoglobin. Individuals with hemoglobinopathies, such as sickle-cell anemia or thalassemia, may also have increased susceptibility to carbon monoxide toxicity (Blumenthal 2001). Rarely, defective motor vehicle exhaust systems may produce high levels of carbon monoxide within the interiors of moving or idling vehicles. “Open-air” carbon monoxide poisoning is a well-known hazard around combustion engine exhaust, even from vehicles in outdoor spaces. Asphyxia and positional asphyxia may occur with vehicle rollovers, entrapment within vehicle restraint systems, or in automatic window or door closure systems. Findings at autopsy are similar to other asphyxia

deaths, with petechial hemorrhages often seen in eyes and intrathoracic cavity and hemorrhage within sinuses and sphenoid processes. Cyanosis, often intense, is present above the restraint area. Often the lividity patterns reflect the entrapment, clothing, and/or vehicular restraints (Fig. 27.3a–e).

Delayed Vehicular Injury

Delayed sequelae of motor vehicle injuries may cause death days or weeks after the motor vehicle accident, following a period of apparent recovery in the intervening time. In these instances, investigative skill is required to correctly ascertain the initiating cause of injury. Chest impacts may produce cardiac contusions, including injury to ventricular free walls, papillary muscles, or the ventricular septum. These injured areas may rupture acutely, causing death (Fig. 27.4). Alternatively, the contusion may result in an aneurysm, infarction, or ventricular rupture days or weeks after the initial injury. Cardiac contusion results from blunt-traumatic impact to the chest with compression of the heart against the sternum and/or spine. The momentarily high intrathoracic pressure with deceleration may also contribute to this type of injury. Abdominal trauma may produce ileus or injury to hollow organs, particularly the small intestine, resulting in rupture and/or peritonitis several days following the injury. Vascular trauma does occur in children, but less commonly than in the adult population (Eddy et al. 1990; Riches et al. 2002; Choit et al. 2006). These vascular injuries usually present acutely with hemorrhage or infarction, but may be delayed in discovery or presentation. Although uncommon, children may also develop pulmonary thromboemboli as a result of local trauma to the leg (Fig. 27.5) or prolonged immobilization and present as sudden death days or weeks later.

Hyperthermia in Vehicles

Death from hyperthermia of infants and children left in cars is well known and increasing in incidence since the recommendation of placing infants in carriers in the back seat. Usually these tragic deaths result from a caregiver forgetting that the infant is in the vehicle. The temperature in closed vehicles may rapidly rise well over the ambient temperature, and car interiors may reach 140° F (60° C) or more within 15 minutes (McLaren et al. 2005). Infants are most at risk for this event since older children may be able to independently leave vehicles and/or alert adults to their presence. Autopsy findings are generally nonspecific in car hyperthermia deaths, although intrathoracic petechiae are often seen (Fig. 27.6). Body temperature at time of discovery is important to confirm hyperthermia; however, this is often not available to the forensic investigator. Interior vehicle temperature is often not recorded and, if available, may not be reliable, as opening the car door will rapidly disperse heat, resulting in an erroneously low measurement. Due to the rapidity of heat exposure in a vehicle, vitreous electrolytes may not demonstrate a dehydration pattern, as is seen in slower exposure to high temperatures. If a victim survives,

complications of disseminated intravascular coagulation (DIC) and multisystem organ failure may be fatal hours-to-days after the hyperthermic event. There is considerable variation in the certification of the manner of death in these tragic events, with some practitioners certifying as accidents and others as homicides.

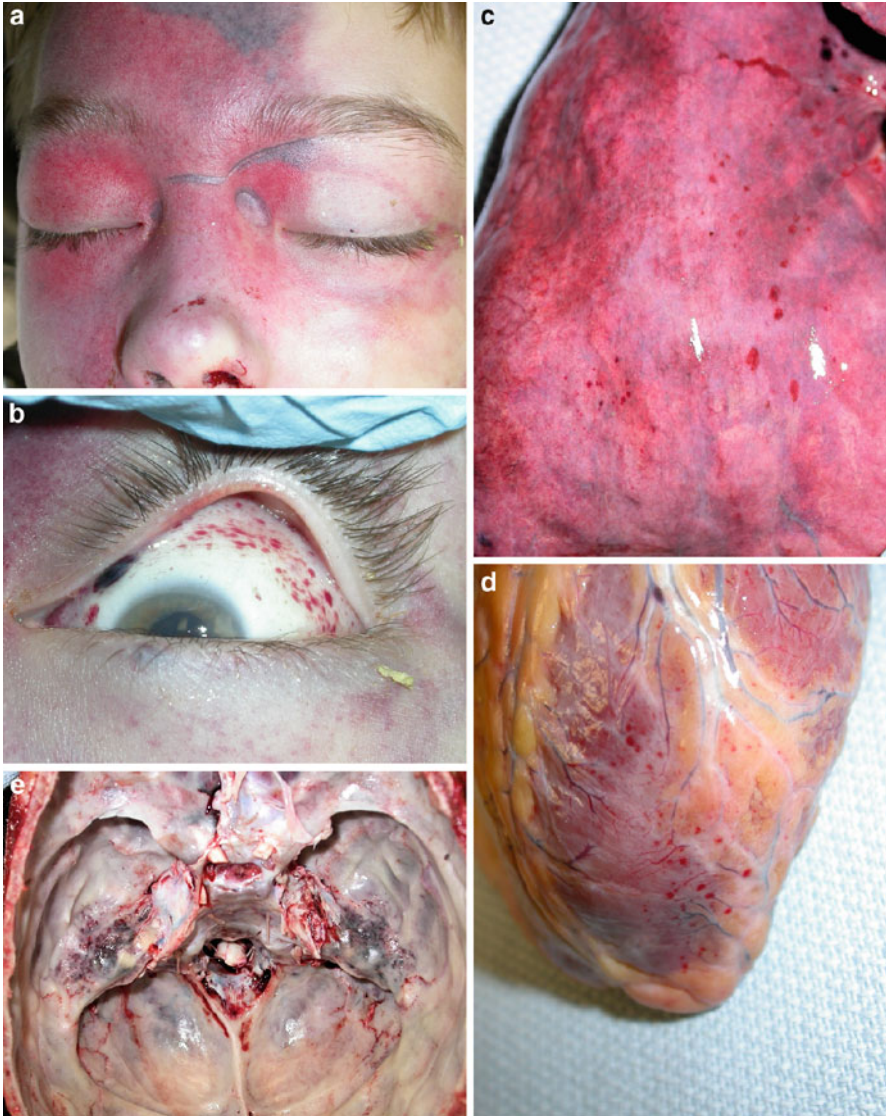


Fig. 27.3 Compression (mechanical) asphyxia and positional asphyxia from an overturned vehicle. This child was compressed in an overturned car with a second vehicle on top. Elements of both mechanical compression and positional compromise were present. There was no anatomically apparent CNS lesion or other traumatic injuries. (a) Florid petechiae, periorbital edema, and

Trains as Vehicles

Collisions with trains, either as an occupant in a vehicle or as a pedestrian, have high fatality rates. In contrast with adult pedestrians who are usually intoxicated and trespassers on rail yards, railroad employees, or individuals committing suicide, child pedestrians may be playing on or crossing rail tracks, riding bicycles or walking next to a moving train, or attempting to board, exit, or ride on top of a train. Traumatic amputations and head injuries are the most common features of these accidents (Thompson et al. 1983; Blazar et al. 1997).

Farm- and Ranch-Related Deaths in Children

Farm- and ranch-related injuries and deaths in children are slowly decreasing in many parts of the world; however, farm and ranch operations remain among the most dangerous occupations, second only to mining, in terms of injuries and deaths (Solomon 2002; Lachowski 2009; CDC 2012b). Unlike mining, children are often involved in farming and ranching activities, exposing them to dangers, both by working and living within farming and ranching environments (Pickett et al. 2005). Most childhood injuries occur in a nonworking capacity rather than being actively engaged in agricultural work at the time of the injury (Hendricks and Goldcamp 2010). Estimates of the cost of injuries and deaths of children on US farms alone exceed 1.3 billion USD annually (Zaloshnja et al. 2012).

Types of Ranch and Farming Injury

There are several dangers in the farm and ranching environment. Heavy equipment is used daily, creating risks for children by operating equipment, riding with others on the equipment, or simply being in the vicinity of operation. Farm machinery is consistently the most common cause of injury and death in both the North American and the UK farm-related incidents (Angoules et al. 2007). Drowning in natural lakes, irrigation

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Fig. 27.3 (continued) lividity patterns contrast with blanched areas of compression. Note the imprint from eye glasses. **(b)** Scleral petechiae from the same child. Numerous petechial hemorrhages, some confluent, are present in the sclera, conjunctiva, and the periorbital skin. Retraction of the eyelid may be necessary to fully appreciate the presence and extent of petechial hemorrhages. Petechial hemorrhages are caused by rupture of small vascular channels, usually venules, and are often present in cases of asphyxia, classically above the point of compression where venous return is compromised. **(c)** Petechiae on the visceral surface of the lungs in the same child. **(d)** Epicardial petechiae from the same child. Visceral pleural and epicardial petechiae were first described as “Tardieu spots” and initially described as pathognomonic of asphyxial deaths. They are commonly seen in asphyxia, but may be present in a variety of non-asphyxial mechanisms of death. **(e)** Congestion and hemorrhage within the inner ear of the same child. Pressure changes from compression may cause sphenoid and inner ear hemorrhages similar to those seen in barotrauma or drowning deaths

Fig. 27.4 Rupture of the cardiac interventricular septum. The injury occurred in a 15-year-old driver involved in a head-on collision with airbag deployment. The driver had no external signs of injury and exited the car, collapsing a few minutes after the accident. The other occupants of the car had minor injuries not requiring medical intervention

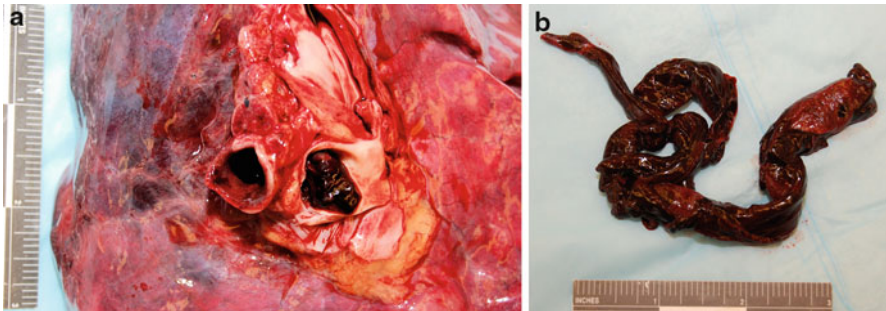
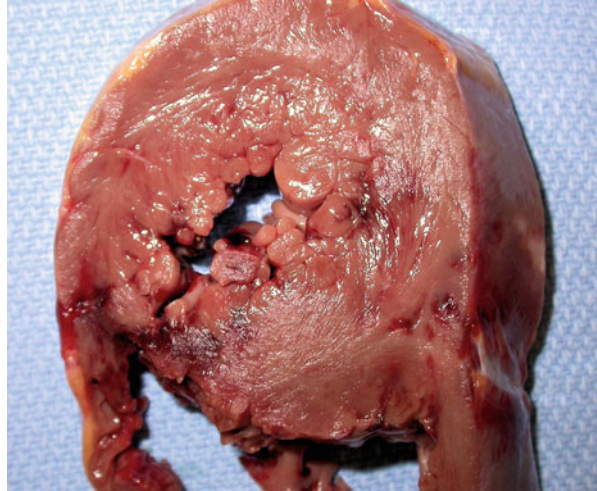


Fig. 27.5 Pulmonary thromboemboli from leg trauma. (a) This 12-year-old boy suffered minor injury to the knee in a bicycle accident, requiring arthroscopic surgery. Five days later, he complained of shortness of breath which improved with rest. He was found deceased one day after complaining of shortness of breath. A saddle pulmonary thromboembolus was found at autopsy. (b) Pulmonary thromboembolus from right-sided circulation. A leg dissection identified the site of thrombus formation at the site of the injury and subsequent surgical procedure

dams, or streams within farms is another common cause of death in farm children. Asphyxial deaths can occur from hypoxic closed spaces or slipping into grain storage bins. Lacerations, skeletal fractures, amputations, and blunt-traumatic injuries result from falls occurring in farming activities or entrapment in farm equipment. Complex tools, firearms, and sharp implements are necessary for farming and ranching and pose a danger of injury and death in children. Falls from, or kicks by, large animals and a wide variety of animal bites also occur more commonly within rural settings. Off-road vehicles, such as ATVs and snowmobiles, are more common in rural settings, increasing the risk of injury and death from the use of these vehicles by children (Lim et al. 2004).

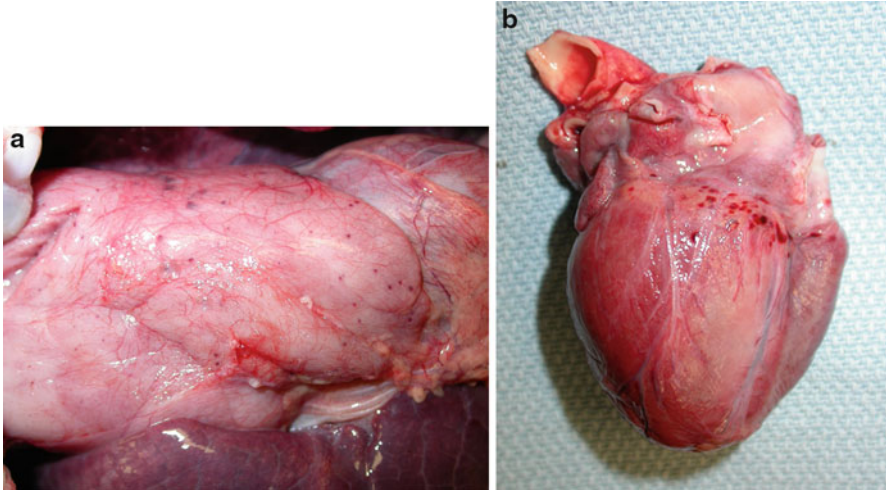


Fig. 27.6 Hyperthermia death in an infant left in a car. (a) This 6-week-old infant was left in the back seat of car for 6 h on a warm day (sunny, 79 °F, 26 °C). Thymic petechiae were seen at autopsy. (b) Epicardial petechiae and hemorrhages were present. Petechiae were also present on the visceral pleural surface. Intrathoracic petechiae are consistently seen in hyperthermic deaths and are attributed to terminal gasping in an auto-resuscitation attempt

Demographics of Farming Injuries

There are minimal gender differences in injury and death in children under the age of 5 years in farm and ranching activities; however, over the age of 5 years, boys have a higher rate of injury than girls (Hendricks and Hendricks 2010). Boys are more involved in hazardous tasks involving heavy equipment and tractors, whereas girls more commonly are involved in animal care and agriculture. Disparities exist for minority populations with higher incidence of injury and death in farms owned by Hispanics, African-Americans, or Native Americans (Goldcamp et al. 2006a, b; Layne et al. 2009). Finally, the remote location and low population density of many farming communities lead to slower emergency response and increased travel time to trauma centers. All of these factors tend to increase the mortality of injuries.

Farming Equipment

Tractors are the leading cause of farm fatalities and injuries in all age groups, but pose several particular hazards to children (Schwebel and Pickett 2012). Inspection of the safety status of tractors in rural Kentucky (USA) revealed significant safety issues in the majority of examined vehicles (Cole et al. 2009). Similar conditions of tractors are likely present in most rural communities and explain the high incidence of injuries and fatalities related to children operating, or present around, this type of

farm vehicle and the diverse forensic findings that may occur in tractor deaths. Nearly half of the tractors examined in the study lacked rollover protection structures (ROPS). Most tractors did not have seat-belt and harness systems, or these systems were difficult to use, putting all operators, particularly young operators or youngsters riding with adults, at risk. Many tractors had a narrow front-wheel stance, creating stability issues and increasing the risk of rollover accidents. Many tractors had loose or damaged seats. Protective shields for starting were present on just over half the trailers examined, and nearly a third had the starting mechanism fully exposed. Rear-wheel fenders exposed operators to moving tires in nearly 40 % of the tractors. Fully functional mounting and dismounting access steps and handrails were present in less than half of the operating tractors and, when present, were designed for an adult body. Many tractors had no functional lights, and nearly 70 % had no rear-view mirrors. Complicating these design and safety issues is the fact that all of these devices are designed for adult operators, not children. Ergonomic studies have demonstrated that even optimally functioning devices may have significant limitations for young operators who have not reached adult stature (Chang et al. 2010). Operation of tractors, equipment, and vehicles is common on family farms well before the age of normal driving licensing. In the USA and Canada, children from farms and ranches have an average of 6 years' experience in driving tractors and other farm equipment on family farms prior to formal licensing for motor vehicles (Marlenga et al. 2001), indicating that many farm and ranch children routinely begin driving farm equipment at the age of 10 years or younger.

Other Farm Injuries

Children on farms and ranches also have higher incidence of falls, lacerations, animal bites, and large-animal blunt-trauma injury. When these are fatal, the trauma is similar to that seen in adults. With any perforating injury, secondary microbial infection may occur. Secondary infections may be more common with injuries sustained on farms and ranches, reflecting contamination with dirt, animal excrement, and other foreign substances present in these environments. Farm and ranch residents may also be exposed to pesticides, herbicides, and a variety of hazardous inorganic chemicals, many of which are not common in urban settings and may cause severe injury and death (Neidich 1993). The use of alternative or supplemental heating, such as woodstoves, contributes to the higher incidence of rural fires and fire-related deaths. Even exposure to hazardous crops, such as tobacco, may be a cause of morbidity in farm children (McKnight and Spiller 2005).

Drowning and Diving Accidents

Drowning is the second leading cause of childhood death by unintentional injury in the USA, the first leading cause in Australia, and the third most common cause in the world (World Health Organization 2012c). Actual deaths may be

higher, since world figures do not account for flooding, tsunamis, boating, and water-transport deaths. Drowning is more common in children under the age of 5 years, a fact likely associated with minimal swimming skills, lapses in supervision, impulsive child behavior, and attraction to water. Drowning is more common in males and often increased in lower socioeconomic classes and minority groups with children of African-American heritage at 1.3 times the rate of Caucasian age-matched children and Native American/Alaskan Native children 1.7 times the rate of Caucasian age-matched children (Centers for Disease Control and Prevention 2012c). Infants and nonmobile children are at highest risk of death in home bathing situations or immersion in buckets containing water. Older children more commonly drown at swimming locations such as pools and natural water sites. Most of the drowning fatalities are related to the child's inability to swim; however, even children with proficient swimming skills acquired in pools or still water may drown with unexpected tidal and current flows present in some natural bodies of water. The contribution of trauma, natural disease, carbon monoxide, drugs, alcohol, hypothermia, or other risks must be investigated in drowning deaths. Many drownings occur when individuals have no intention of entering the water, that is, falling off docks or boats, water-transport accidents, or breaking through ice in a snowmobile or car. According to statistics of the International Life Saving Federation (ILSF), approximately 25 % of drownings occurs in individuals with swimming skills, or in water less than a meter deep, and 40 % within 2 m of the pool edge or shore (International Life Saving Federation 2012).

Pathophysiology of Drowning

Drowning is an asphyxial death resulting from immersion in a liquid, usually water, with resulting anoxic changes. "Near drowning" is defined as a recovery or resuscitation following submersion/immersion. Following a "near-drowning incident," individuals may recover completely or succumb at a later time from complications of anoxic injury and secondary medical complications. Rarer occurrences of drowning deaths include "hyperventilation drowning," seen in swimmers, usually youths, who hyperventilate to increase underwater swimming distance. The resultant hypocarbia may decrease the physiological stimulus for air, resulting in anoxia, unconsciousness, and subsequent drowning. "Secondary drowning" and "delayed drowning" are terms used when an individual, often a young child, aspirates water and appears to recover but develops a sudden deterioration of pulmonary function several hours after the event. Some use the term "immersion syndrome" when an individual has a catastrophic event, usually cardiovascular, while in the water and dies from the precipitating event or loses consciousness, resulting in drowning. Certification of these immersion-syndrome deaths may be problematic and is often classified as accidental drowning when the precipitating event cannot be recognized or proven.

A consideration of potential components of drowning assists in the forensic interpretation of findings (Burford et al. 2005). The pathophysiology of drownings involves lung and airway effects with resulting cerebral anoxia. In most drownings,

the initial insult results from water within the airways and lungs causing inadequate oxygenation. Aspiration of mud, debris, sand, or vomit into the bronchial tree and alveoli may also occur and complicates the physiological response. This also increases the risk of acute respiratory distress syndrome (ARDS), chemical pneumonitis, and pneumonia if the individual is successfully resuscitated. Freshwater inactivates pulmonary surfactant on contact, resulting in atelectasis, further complicating oxygenation and increasing the pulmonary blood shunting physiological response. Osmotic forces may draw more fluid into alveoli from pulmonary intravascular spaces. The resulting anoxia and acidosis have the most immediate and consequential impact on central-nervous-system (CNS) function, although other organ systems may be involved in pathophysiological changes. These changes include cardiac dysrhythmias, blood-pressure changes from catecholamine release, carbon dioxide retention, and hypothermia. Metabolic acidosis is significant in “near-drowning” victims. Although initial experiments suggested that fluid and electrolyte imbalance and hemoglobin/hematocrit changes from osmolality differences played a major role in drowning, these changes may not be as common or as important as first thought. Deaths are reported in “secondary” or “delayed drowning” scenarios where acute lung injury and rapid pulmonary failure from inhaled water, debris, or chemicals within water produce death several hours after the event.

Autopsy Findings

Forensic findings in all drowning deaths are nonspecific; thus, drowning is a diagnosis of exclusion. Numerous tests have been proposed for establishing the diagnosis of drowning, including diatom presence and electrolytes or other substance differences in right versus left cardiac blood; however, none have proven sufficiently valid for forensic use. Tenacious froth, often with slight blood tingeing, may be present in the mouth and nares and is thought to result from an admixture of water, pulmonary surfactant, mucus, and blood plasma protein (Fig. 27.7). This finding is supportive of drowning but is not present in all cases, and the absence should not be used as criteria for excluding drowning. Internally, froth and water are often present in the airway; the lungs are often heavy and edematous. During the process of drowning, individuals may swallow large quantities of water, distending the stomach. This constellation of heavy, waterlogged lungs often with water in the stomach is termed “wet drowning” and is present in the vast majority of drowning deaths; however, in a minority (about 10 %) of drownings, there is no water in lungs, airways, or stomach. Laryngospasm is postulated to occur in these cases closing the airway and resulting in “dry drowning.” In all drowning cases, the struggle to breathe or submersion below 2 m of water may also result in pressure changes reflected in hemorrhage in the inner ear and sinuses that may occasionally be seen at autopsy (Fig. 27.8). Hemolysis of red blood cells may be present if copious quantities of freshwater are present. Often lividity patterns have a bright red tone when drowning has occurred in cold water (Fig. 27.9). All of these findings however are nonspecific and may occur in other deaths. Conversely, drowning may occur with none of these signs. Finally, in deaths from “near drowning” or



Fig. 27.7 Foam cone in drowning. This 6-year-old child drowned in freshwater. A tenacious froth, often blood tinged, exudes from the nares and/or mouth in many drowning deaths. It is caused by agonal breathing and the mixing of air, water, and respiratory mucous. It may extend to the trachea and more distal bronchi. Although commonly seen in drowning, it is not specific; drownings may occur without this finding, and similar froth may be seen in other non-drowning deaths, such as acute drug overdoses/toxicities

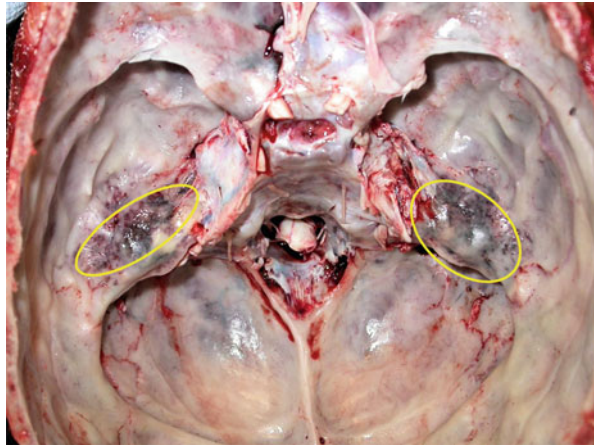


Fig. 27.8 Hemorrhage in the mastoid sinuses in drowning. This is a common, but nonspecific, finding in drowning and is thought to be related to pressure changes

“secondary drowning,” the findings at autopsy will more closely reflect the anoxic and secondary complications rather than the original drowning event.

Forensic investigations of all drowning deaths should rule out the presence of trauma or other incapacitating events eg. (insect/aquatic stings, traumatic falls, entanglement in docks/ropes/flora, fatigue) as a component to the drowning. The presence of natural disease, including cardiac arrhythmias, epilepsy, metabolic derangements (eg. diabetes), and other potentially incapacitating conditions, should also be investigated in drowning fatalities. Carbon monoxide is present, often in

Fig. 27.9 Skin coloration in cold-water drowning. Lividity patterns may have brighter red tones in cold-water drowning, hypothermia, or refrigeration. Carbon monoxide can also produce a cherry red coloration and should be investigated in any drowning where the potential exists for exposure to internal combustion engine exhaust



lethal levels, in boats and around other internal combustion engines, and carbon monoxide quantitation should be performed in any water- or near-water-related death in which gas-powered engines were possibly present in the vicinity at the time of the incident (Jumbelic 1998). Routine drug and alcohol screening should be performed to rule out incapacitating toxicities such as alcohol or opiate intoxication. Depending on potential medical and other case findings, additional toxicology or clinical testing, including vitreous electrolyte, ketone, and glucose levels, may be helpful (Byard and Summersides 2011). Forensic investigations of drowning deaths should document water temperature to assess the potential role of hypothermia in the context of the case. If there is a possibility of diving contributing to the death, careful neck examination, including a posterior neck dissection and cervical spinal cord examination, should be performed to rule out contributions to neck and cervical injury.

Fire Deaths and Burns

House Fires

Fires and burns are a common cause of injury and death in children throughout the world (International Association for the Study of Insurance Economics 2009). Burns are usually unintentional, but may be intentionally inflicted. In house fires, children under 4 years are at the highest risk of death, followed by the elderly (Centers for Disease Control and Prevention 2010). Fire deaths have striking disparities in occurrence, with victims more likely to be from a lower socioeconomic group and of Native American or African descent as compared to Caucasians (Istre et al. 2001; Flynn 2010). The incidences of both fires and fatalities are higher in rural areas contrasted with urban populations.

Most fire deaths occur in the home, particularly in homes without working smoke detectors. Infants and very young children are at greater risk of succumbing

to fire- and combustion-related injury due to the presence of fetal hemoglobin-related carbon monoxide toxicity and the inability to recognize and appropriately react to the fire. Children may tend to hide within the house or seek out sentimental items, such as personal belongings or pets, delaying their escape from the burning house. Young children may be the cause of the fire, resulting from inappropriate use of matches, lighters, and candles, and are thus at the fire's origin and are therefore exposed to the first effects of the fire.

Fire Components Relevant to Forensic Findings

A brief analysis of the components of fires is helpful in understanding the forensic findings (Peck 2011). Smoke is readily produced in fires, particularly home fires, and comprises the airborne solid and liquid particulates of combustion. Smoke is a direct eye and pulmonary irritant and is invariably accompanied by the toxic gas carbon monoxide (CO) with environmental levels of 5 % or more. The carboxyhemoglobin (COHb) saturation level in a human exposed to this level of CO gas will rise to 40 % or more within 30 seconds (Peck 2011). Other toxic gases such as hydrogen cyanide (from synthetic fibers or materials) or the highly irritating acrolein (from wood and natural products) may also be present (Einhorn 1975). Concomitantly, environmental oxygen levels in the fire environment diminish from the consumption of oxygen by combustion. Humans become significantly physically impaired with oxygen levels below 17 %, and mental judgment is compromised at 14 % (Peck 2011). House fires may smolder with oxygen levels at 12 %, and all fires have an oxygen-deficient environment. The hypoxic environment likely contributes to fatalities in fires, but this impact cannot be directly measured by current technology used at autopsy.

Thermal conditions of a fire are also important to some forensic findings (Peck 2011). Temperatures in most house fires reach 300 °F (150 °C) within 5 minutes. In some structures, such as an aircraft, much higher temperatures (approximately 1,100 °C) may be present within 2 minutes. A fire often reaches a “flashover” point, where the thermal radiation causes surfaces to reach their ignition temperature. At this point, near-simultaneous ignition of materials occurs, and the fire spreads to involve the complete room or structure within seconds. Temperatures may soar at this point to over 2,000 °F (1,000 °C) within the structure. Similar rapid acceleration in combustion and temperature may occur when partial collapse of a structure or opening a door creates a rush of oxygen causing rapid fire growth.

Autopsy Findings in Fire Deaths

All fire deaths must be autopsied to confirm the identity of the victim, establish the cause of death, and eliminate non-fire causes of death. The autopsy should include

Fig. 27.10 Soot and froth of pulmonary edema in fire deaths. Soot is often present in the nares of fire victims. A slight froth of pulmonary edema may also be present. The presence of soot in the nares and mouth is nonspecific and may occur postmortem



full-body radiographic studies to detect debris, projectiles, or skeletal fractures especially if the external examination is compromised by extensive fire damage. In many children, particularly infants and small children, dental identification is precluded due to the immature developmental stage of dentition and the lack of dental records. This may require investigators to seek DNA confirmation of identity when visual identification is not straightforward. Although rare, temperatures and duration of house fires may reach cremation thresholds, resulting in limited remains of small individuals, including children, necessitating thorough scene examination. In these instances, assistance from a forensic anthropologist may be helpful in increasing the percentage of remains recovered.

The abundant smoke of most house fires is demonstrated at autopsy by readily apparent soot present in nares (Fig. 27.10) and airways (Figs. 27.11 and 27.12). The presence of soot below the true vocal cords is indicative of breathing soot-filled air and is not a fire artifact. In conjunction with the thermal injury, carbon monoxide saturation may be within the lethal range and may play a more significant role in causing the death as compared to the thermal injuries. Pulmonary edema and froth in the nares (Fig. 27.10) and upper airway are often present. Skin blistering may be present (Fig. 27.13), and geographic desquamation of the hands, also

Fig. 27.11 Soot in the airways in fire deaths. Soot deposits in the trachea below the true vocal cords are indicative of breathing while in a smoke-filled environment. The soot often extends to deeper bronchioles. Hyperemia and edema are commonly present in the mucosal airway surfaces

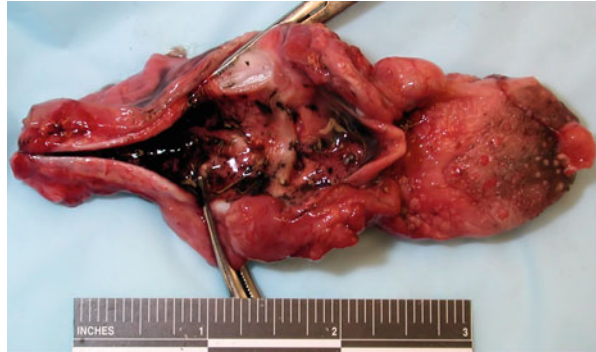


Fig. 27.12 Microscopic soot deposits in fire deaths. A thin layer of carbonaceous soot is appreciated within the mucus and sloughed epithelial cells in this section of trachea from a fire victim (Hematoxylin and Eosin, H&E $\times 200$)

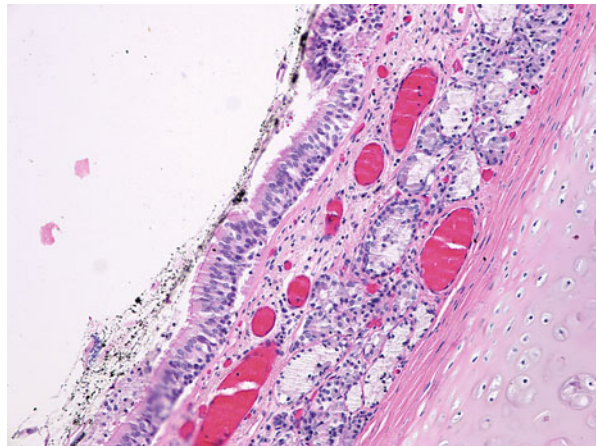


Fig. 27.13 Skin blistering in thermal injury. Skin blistering is common in fire victims. This may be from direct thermal injury or may occur postmortem as an artifact of the fire/heat

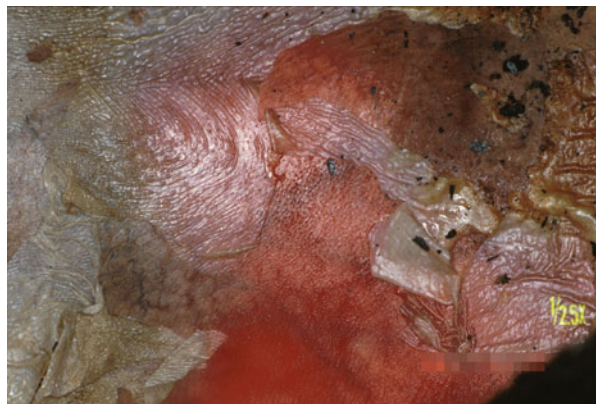


Fig. 27.14 “Degloving” in thermal injury. The epidermal layer may blister and “deglove” in fire deaths. This is usually a postmortem artifact. Fingerprint impressions may be made from the “glove” to aid in identification if suitable pre-injury prints are available for comparison



Fig. 27.15 Tracheal hyperemia in thermal injury. In flash fires or steam burns, there may be minimal soot deposition within the airway. The trachea may be intensely hyperemic from burns of superheated air. Edema is often present



referred to as degloving, may occur (Fig. 27.14). More severe heat injury results in extensive charring and reduction in body mass, sometimes with marked reduction in the size and bulk of the extremities and head. Bodies may assume the so-called pugilistic posture, a postmortem artifact of heat-related, differential muscle contraction.

Victims of “flashover” fires or explosions, such as from natural gas leaks or incendiary devices, often have minimally elevated or normal carbon monoxide saturation levels and an absence of soot in the airways, which may be intensely hyperemic (Fig. 27.15). In this scenario, death is usually related to heat-induced laryngospasm or vagal-reflex cardiac arrhythmia. Pulmonary contusion or hemorrhage may be present from blast injuries if an explosion has occurred; debris or bomb material may be embedded in the victims. Hemorrhage in the inner ears and sphenoid processes may be apparent at autopsy in such explosions and subsequent fires.

Fig. 27.16 Skin splitting artifact in thermal injury. Skin splitting in fires is a known postmortem artifact and should not be mistaken for sharp force injury. Note the yellow base of the surface and lack of vital reaction. The slight reddish appearance is from drying



Traumatic Injury in Fires and Fire Artifacts

Traumatic injuries, falls, and blunt trauma from structural collapse may be present in fire fatalities. These injuries may be the primary cause of death, contribute to the cause of death by restricting egress from the fire, or occur postmortem. Heat-related fractures of bones, including the skull, occur in fires and should not be mistaken for premortem injury. A common fire-related artifact is an epidural accumulation of blood and marrow; however, this is readily distinguished from a premortem epidural hematoma by the granular, foamy, or flaky texture and brownish coloration. The victim's skin may be dry with large splitting defects exposing the underlying fascia or abdominal cavities (Fig. 27.16). Clothing or objects near the victim may burn or melt and be deposited on the skin. Care must be taken to distinguish these postmortem artifacts from actual premortem injury.

Additional Procedures and Testing in Fire Deaths

Assistance from anthropologists is helpful in many fires to accurately recover and identify bone fragments which may be difficult to recognize among fire debris at the scene (Figs. 27.17 and 27.18). Radiological examination is extremely helpful, but suspicious findings must be confirmed by direct examination (Fig. 27.19).

Toxicology testing for alcohol and drugs is important in fire fatalities, since the use of these substances may contribute to the start of the fire or failure to successfully leave the burning structure. Testing for carbon monoxide is needed in all fire deaths, and testing for additional toxicants (such as cyanide) may be necessary for a complete forensic investigation. Select cases may benefit from CO saturation levels at different anatomic sites; for example, CO saturation of a fresh subdural hematoma or an area of trauma may reveal different levels compared with to cardiac blood, indicative of prefire trauma contributing to death. In cases where there are no/minimal airway-soot

Fig. 27.17 Bone fragment in fire death. Portion of long bone retrieved from a fire. The irregular fragmentation and splitting is a postmortem artifact and does not indicate traumatic premortem injury to bone



Fig. 27.18 Bone fragment in a fire death. Microfissures within a long-bone fragment. Small-bone fragments such as this may not be recognized by responders. Consultation with forensic anthropologists is extremely helpful in the recovery of human material in a fire scene

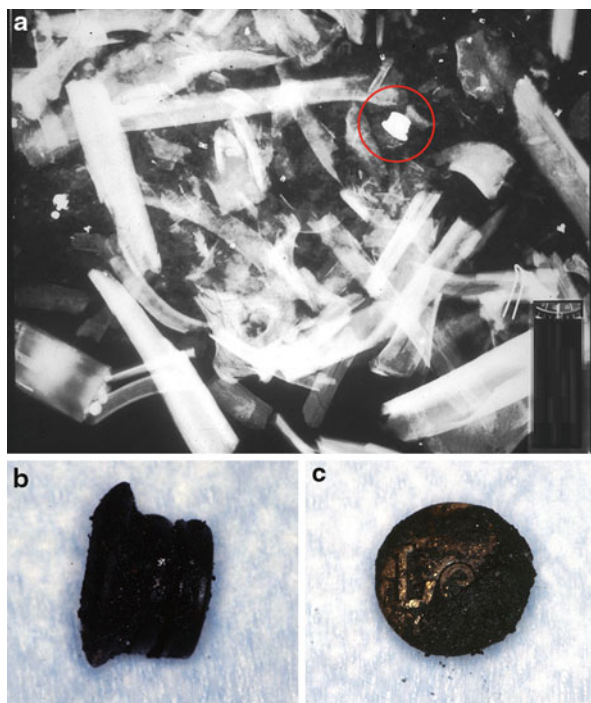


and nonlethal-CO saturation levels, death prior to fire must be seriously considered in the investigation. If an incendiary device is suspected, consultation with experts at the time of the initial investigation and autopsy will assist in the specialized collection of evidence from victims which is required for case investigation.

Scalding

Contact with or immersion in hot liquids or gases is more common in infants and small children than adults. Scalding is the most common burn injury in the pediatric age group (Shah et al. 2011); however, most accidental scalding injury is not fatal, so this is less commonly encountered at autopsy. The skin in a scalding injury is markedly erythematous, blistered, or, with severe injury, completely denuded with intense underlying erythema. Sharp borders are invariably present between injured and uninjured areas. A characteristic of scalding injury is the distinctive injured/uninjured pattern created by different modalities of injury, including pouring, splattering, or immersion. In an accidental scalding injury, irregular patterns of splattering are often present on the face, hands, or upper body often from children pulling or tipping pans of hot liquids from stoves. In immersion injury, larger, more confluent areas of burning are seen which correspond to the child being dipped or held in hot water. The buttocks, back, and feet are

Fig. 27.19 Misleading radiologic image in a fire death. These fragments were recovered from a house fire. Routine radiologic imaging showed a radio-opaque object suggestive of a projectile (a: circled). Retrieval and subsequent cleaning of this object (b, c) demonstrated it was a metal button from jeans



the most commonly burned areas. Characteristic of the immersion burn is the sparing of injury in skin folds, such as inguinal regions or behind the knees, resulting from the child withdrawing the lower extremities to avoid the immersion. Large-immersion pattern scalding injury is indicative of inflicted trauma. Children under 4 years of age are most at risk of immersion injury, and this form of inflicted trauma is often precipitated by adult frustration with toilet training of the young. Deaths from scalding injuries result from direct thermal injury or complications of these injuries. Vitreous chemistry and microbiological studies may be of value in investigating these deaths.

Water is the most common medium for scalding injuries, likely due to its universal availability. Infants' and young children's skin is more susceptible to thermal and scalding injury (Diller 2006), and burns can occur within 3 seconds with water temperatures 140 °F (60 °C) or higher (Feldman et al. 1978, 1998). Many residential water heaters are set to this temperature or higher, increasing the risk and ease of injury to children.

Chemical Burns

Fatal chemical burns are uncommon in pediatrics but may occur in young children from exposure to caustic household chemicals, such as lye (Elshabrawi and A-Kader 2011). Most of the fatal injuries involve ingestion, and deaths may occur following prolonged medical intervention.

Surface Burns

Contact with hot objects is a cause of childhood burns and is often seen in child abuse (Toon et al. 2011). In the forensic setting, these are usually a component of an inflicted-injury pattern and not the primary cause of death. In many instances, patterned impression of the causative object, such as a hot plate, cigarette, poker, or other object, is present. It is critical to document these pattern injuries with extensive photography and detailed measurements. As with other patterned injuries, body curvature and positioning may cause interrupted patterns or may assist in interpretation of body posture or defensive positioning when inflicted.

Fireworks

Deaths from fireworks are rare, but a large percentage of these fatalities are in children. Deaths usually result from blunt-traumatic injury and/or flash fire resulting from fireworks (Smith et al. 1996). Rarely blast and explosive injuries are a component of these deaths.

Delayed Fire and Burn Deaths

In many burn injuries, death occurs after considerable time has passed from the time of the injury with numerous intervening medical and surgical procedures. The original pattern of burn injury may not be present, and there are usually a number of medical complications leading to the demise. Burn victims are susceptible to a wide variety of infections, electrolyte and metabolic derangements, and medical complications including ARDS, DIC, and multisystem organ failure. Careful documentation of medical interventions and events is part of the forensic autopsy of these patients. Death certification must accurately relate medical complications back to the initiating injury.

Electrocution

Most childhood electrical fatalities result from low-voltage electrocution in the home (Rabban et al. 1997). Household appliance cords or extension cords are the most common causes of electrocution in children, followed by wall outlets. Younger children may contact cords orally or via a conductive foreign object such as a key or pin. Less commonly, contact with poorly grounded and electrified appliances or heaters may cause electrocution. High-voltage electrocution is rare in young children but may be seen in adolescents, particularly among males. An even rarer event is death due to lightning injury in the pediatric population; however, fetal death due to maternal electrocution may be seen even when the mother survives the lightning strike.

Fig. 27.20 Electrical injury: Joule burn. The point of electrical contact may be subtle. These cutaneous injuries are from a 2-year-old child who touched a poorly grounded electric space heater while sitting in a water-filled bathtub



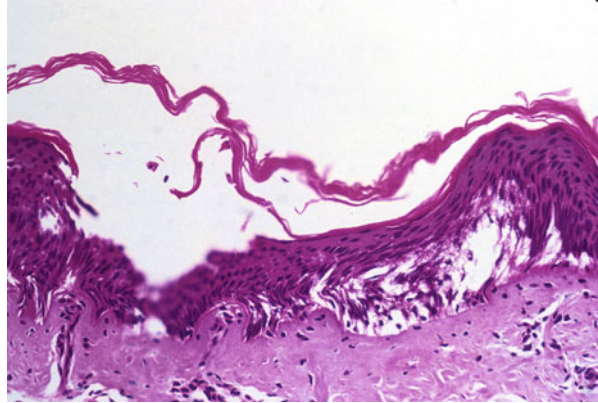
Fig. 27.21 Electrical injury: contact site. The epithelium is often raised and pale white with a central point of contact and mild hyperemia at the base



Low-Voltage Electrocutation

The findings of electrical injury in children are similar to those seen in adults, and the elements of forensic investigation and autopsy are identical. Electrical injury is challenging since often there are no distinguishing features. A high index of suspicion, through scene investigation and consultation with electricians, is critical to identifying and appropriately categorizing these deaths. Low-voltage (<1,000 V) electrocution is the most common type of electrocution in both children and adults. The classic “Joule burn” or electrical mark is present in approximately half of the cases. When present, it identifies the point of electrical current entering or exiting the body. The skin may be whitish (Fig. 27.20) surrounding a raised, oval, or round crater with hyperemic borders and a pale center (Fig. 27.21). The shape of the burn may relate to the conductor shape in contact with the skin. Charring or edema is often present, and prolonged contact may result in deep burning of tissue. Microscopically, a “streaming” appearance of cells and nuclei is often present accompanied by thermal homogenization of the dermis, deep fascia, and underlying tissue

Fig. 27.22 Electrical injury: histology of a contact site. On microscopic examination, there is a “streaming” appearance of the cells and nuclei, often with thermal homogenization of the dermis, deep fascia, and underlying tissue (Hematoxylin and Eosin, H&E \times 400)



(Fig. 27.22). The epithelial basal layer of the skin is often detached. These changes are supportive, but not diagnostic of electrical injury. Occasionally, trace evidence of metal deposition from wires may be present at the site of electrical contact. The point where electric current exits the body is usually more difficult to identify and may be entirely absent. When present, it may have many of the characteristics of the site of current entry. Deaths from low-voltage electrocution are caused from electrical disturbances, primarily ventricular fibrillation of the cardiac conduction system or respiratory paralysis from interference with brainstem function, both autonomic disturbances that leave no physical trace to be identified at autopsy.

High-Voltage Electrocution

High-voltage electrocution (over 1,000 V) is uncommon in the pediatric population and, when present, has the same characteristics of blast injuries and flash burns as with adult deaths due to high-voltage electrocution. Death is usually related to blast effects, thermal injury, and secondary trauma rather than to an electrical interruption of cardiac or brainstem function. With extremely high voltage, charring and bone fusion may be present, and the muscles will appear gray-white from the effects of temperature. Skin may be denuded, and the hair is often scorched or a lighter color following high-voltage electrocution.

Lightning

Lightning strikes are uncommon events, and, because of the extremely short time interval of electrical exposure, over two-thirds of victims survive a lightning strike. In the event of a death, the majority of findings may be nonspecific. A faint, erythematous, arborizing pattern on the skin, the so-called Lichtenberg figure, may be present initially, but will subsequently fade in a relatively short time frame. Rupture of eardrums and opacification of corneas may occur in lightning injury.

Falls

Falls are a part of normal childhood, an expected result of the need for exploration, as the young push their limits in developing coordination and locomotion skills while navigating their environment. Most falls are inconsequential; however, each year in the USA, 2.8 million children seek emergency department care for falls (Centers for Disease Control and Prevention 2012d). Analysis of fall data in children can identify intervention strategies to reduce this common cause of injury (Khambalia et al. 2006). Falls are responsible for death in over 46,000 children annually (World Health Organization 2012a) and may be a component of inflicted injury of children. Delineation of these injuries is one of the most challenging tasks in forensic pathology.

Types of Fatal Injury in Falls

Fatal injury from falls usually involves trauma to the head, although extremity fractures and internal injuries can occur and may cause death. The assessment of the degree of injury relative to the presenting story is a key component in distinguishing accidental and inflicted injury in the evaluation of a fall. In general, short-distance falls (less than 10 ft or 3 m) and falls down stairs rarely produce fatal injury to children (Chadwick and Salerno 1993; Chadwick et al. 1991; Chiaviello et al. 1994a). The presence of an adult may complicate injury to the child as falls occurring with children being carried down stairs by an adult have a higher injury index and more frequent skull fractures than falls down stairs by children themselves (Joffe and Ludwig 1988). The added mass of an adult and secondary impact(s) may be responsible for the increased severity of injury. Numerous studies of falls in specific situations exist in the literature including falls from buildings (Vish et al. 2005), playgrounds (Centers for Disease Control and Prevention 2012a; Petridou et al. 2002), beds/couches (Belechri et al. 2002), high chairs (Schalamon et al. 2006), infant walkers (Shields and Smith 2006; Chiaviello et al. 1994b), child-restraint seats (Desapriya et al. 2008), infant slings/carriers worn on adult bodies (Frisbee and Hennes 2000), heights (Thompson et al. 2011; Murray et al. 2000), and in hospital settings (Jamerson et al. 2009). Case reports of severe injury from accidental stairway and short-distance falls exist (Lantz and Couture 2011), although the presence of severe head injury is more indicative of inflicted trauma.

Disparities

Disparities exist in pediatric falls. Falls with injuries are more common in children of nondominant populations and lower socioeconomic classes (Faelker et al. 2000; Shenassa et al. 2004) in most but not all countries (Engström et al. 2002). This is correlated to older and poorer conditions of environmental factors, such as reduced

repair of playground equipment, older model cribs and beds, and poor maintenance of stairwells, balconies, and windows in lower socioeconomic populations.

Investigation and Autopsy

Forensic investigation and autopsy in childhood deaths from falls is challenging since inflicted versus accidental trauma is often the question. Careful and extensive photography of injuries, full radiological examination, fixation of the brain, and extensive histology are considered a baseline in the performance of the autopsy. Specialized dissections, such as removal of optic nerves, eyes, and posterior neck dissections including examination of cervical spinal roots (Matshes et al. 2011) may assist in interpretation. When there is a question of inflicted skeletal trauma, removal of the affected bone and the contralateral control bone may be important for evaluation. Careful review of all clinical records and police investigation is required for optimal interpretation. Correlation or identifying points of discordance with the given clinical history of how the event occurred is critical for case assessment. It may be helpful to have at least one meeting with all interested professionals, including clinicians providing care, radiologists (if appropriate), police and investigating agencies, child-protective services, and legal prosecutorial representation if jurisdictionally allowed. The adage “We speak for the deceased as discoverers of truth, not makers of cases” rings true in evaluation of the difficult area of pediatric deaths due to falls.

The rapid advances in imaging and pediatric head-trauma interpretation will likely assist in defining appropriate studies and interpretations as more evidence-based practices in forensic medicine evolve.

Animal-Related Deaths

Most children have many positive exposures to animals – from appreciation of wild animals, visits to zoos, and caring for animals as pets, companions, or livestock. Care and responsibility for animals is a major step in normal childhood development; abuse of animals is a critical warning sign of behavioral problems. With this overarching exposure to animals, childhood injuries and fatalities occur in a variety of animal-related scenarios (Bury et al. 2012a, b). The majority of these fatalities occur either with large animals or with commonly encountered animals such as dogs.

Horses and Other Large Animals

Injuries and deaths associated with large animals are increasingly seen both in and outside rural environments. The non rural increase is primarily due to the popularity

of horseback riding among urban and suburban youth. A horse can weigh over 1,000 lb (450 kg) and reach speeds approaching 40 mph (65 km/h), both accounting for the inherent dangers of this sport. This danger is amplified for young children where the injury rate for children in horseback riding is nearly twice that of adults from both falls and kicks from horses (Jagodzinski and DeMuri 2005). A Mexican proverb states “It is not enough for a man to learn to ride; he also must learn how to fall,” alluding to the danger admixed with the joy of this sport.

Most injury in horseback riding occurs when the rider falls off the horse; occasionally, this is complicated by a secondary kick from the horse, being stepped on by the horse, or through entrapment in a stirrup and subsequent dragging. The use of “break-free” stirrups can decrease the risk of entrapment and dragging following a dismounting fall. In nearly a third of horse-related injuries, the child is not riding the horse, but is kicked while in the vicinity of the horse. Head injuries are the most common and the most serious type of injury, accounting for most fatalities in horse-related accidents (Ghosh et al. 2000). In children, upper-extremity injury is more common than lower-extremity injury. Injuries to the back, pelvis, chest, and abdomen do occur, but with much less frequency in children as compared to adult horse enthusiasts. Horse-related injury is second in severity only to pedestrian versus motor vehicle injury, and horse-related injury has greater severity than injury from ATVs, bicycles, and passenger-related motor vehicle crashes (Bond et al. 1995). Helmet use reduces the severity of injury and the likelihood of death.

Dog Bites

Nearly five million dog bites occur every year in the USA, with over 40 % occurring in children under 14 years of age (Centers for Disease Control and Prevention (CDC) 2001). Children, particularly those under the age of 5 years, are more likely to have provoked dogs, often unintentionally through play, and are often incapable of escape or defending themselves from a dog attack.

Most dog bites are generally single bites to the extremities and are usually not fatal; however, most dog attacks and fatalities involve multiple bites to the head and neck region where extensive mutilating and defleshing injuries may occur. Exsanguination and air embolism via neck veins are common causes of death in dog attacks. Most dog-attack fatalities have multiple puncture wounds from the teeth and extensive defleshing from the tearing and hunting behavior of the dog(s). Severity of injury and increase in fatal attacks may be increased when more than one dog is involved due to “pack” behavior (Tsokos et al. 2007). Abrasions and shallow incised wounds from paws or friction contact abrasions from surfaces may also be present. Large breed dogs may cause crushing injuries to the very young, including infants and toddlers, resulting in severe skull fractures and cerebral injuries. Several studies have examined the incidence and breed characteristics of fatal dog attacks, but may be confounded by the lack of accurate data into breed

type actually present in a community as well as the effects of legislation restricting ownership of certain breeds (Raghavan 2008; Sacks et al. 2000). Bite-prevention programs show initial promise in educating young children about safe behavior with dogs (Meints and De Keuster 2009).

Special considerations at autopsy of a fatality involving a dog bite include documentation of any canine odontological trauma for comparison (De Munnynck and Van de Voorde 2002). When an animal is captured, examination of material between the teeth or within the gastrointestinal tract at necropsy may confirm human tissue. Consultation with veterinarians is very useful for testing of an animal for rabies, tumors, or other conditions that may have led to the attack, including examination for prior animal maltreatment, starvation, or training for fighting activity. Investigation of the events leading to the attack, including a history of dog behavior, breed characteristics, and any precipitation or provocation by the victim, is helpful in reconstructing the events and interpreting injury patterns.

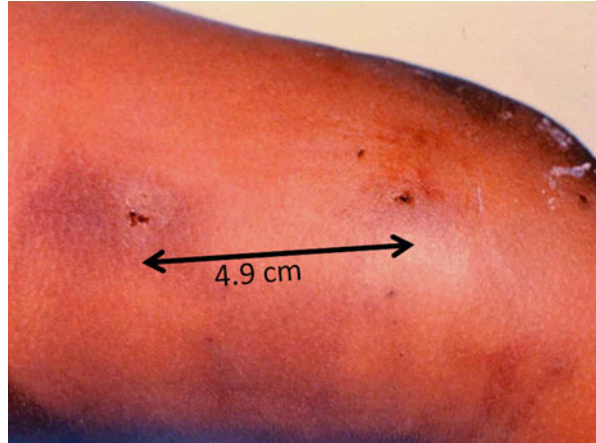
Bites and other trauma from animals may also be a cause of delayed death from microbial infections contracted from oral animal flora, human skin flora, or subsequent contamination of the original bite (Dendle and Looke 2008).

Other Animal-Related Deaths

A wide variety of wild animals, on both land and sea, may cause injury and death in both provoked and unprovoked attacks. Children are often more susceptible due to their decreased ability to flee or defend themselves, lower cognitive awareness of danger, and provoking animal attack behavior either intentionally or through play. The smaller mass and stature of young children also increases risk of fatal outcome of a wild-animal attack. Many animals may attack causing injury and death including bears, feral dogs, coyotes, cougars, and wolves on land and sharks or other predatory fish in the sea. Predatory land animals usually maul and bite victims, and if hunger precipitated the attack, the predators may devour most of the victim. Large non predatory animals, such as cattle or moose, may cause injury and death from a stampede or trampling of victims.

In water, sharks are the most common human predator. Sharks may swim very near land and docks and attack surfers and swimmers. Shark attacks are characterized by large bites and tearing of limbs and viscera. Examination of the body for bite marks or fragments of teeth may assist in species identification. Crocodiles and alligators are territorial animals and may attack individuals within their home wetlands. Alligators are generally timid but may lose their fear of humans when fed or with repeated contact. In contrast, large crocodiles are more predatory by nature. Both species can move very fast on both land and in water, increasing the danger of attacks to small children. These species will occasionally drag victims underwater, preserving a portion of the body for later consumption. Their jaws exert the most pressure of any predator (Erickson et al. 2012), with up to 3,700 lb per

Fig. 27.23 Cutaneous site of a snake bite. This 3-year-old child collapsed suddenly while playing in the tall grass at a campsite. Her family reported a single scream before the collapse. She was unresponsive and could not be resuscitated. Later, this site of likely envenomation was found on her thigh



square inch pressure (25.5 MPa, 255 bar, 251 ATM), causing instantaneous massive trauma to victims. All these predators produce findings in child victims similar to those seen in adults, although children may be more susceptible due to their small size and inability to defend or flee from an attack. Rarely, smaller sea life may sting or envenomate victims, causing injury or death, by either venom or secondary drowning. In all these animal attacks, the findings at autopsy are similar to those in adults. With the wide variety of animals and predators throughout the world, forensic pathologists should be aware of regional species that may cause injury and death.

Venomous Creatures

Fatal envenomation may occur from several land-based (snakes, scorpions, spiders) or marine-based creatures (jellyfish, stonefish, octopus, Portuguese man-o'-war, cone snails). Autopsy findings vary with specific venomous species and may be subtle, requiring detailed historical investigation and/or careful cutaneous evaluation for envenomation site (Williams and Milroy 2012). Venomous-snake fatalities are uncommon, but young children may be particularly susceptible due to their small body mass (Figs. 27.23–27.25).

Insects

Insect bites and stings may also produce death from anaphylaxis, zoonotic transmission of disease, or rarely overwhelming envenomation. Worldwide, the deadliest “animal” is the mosquito, causing malaria across wide areas of the tropics as

Fig. 27.24 Dissection at site of snake envenomation. Hemorrhage is clearly present in the subcutaneous tissue tracts, and direct envenomation of an artery is identified

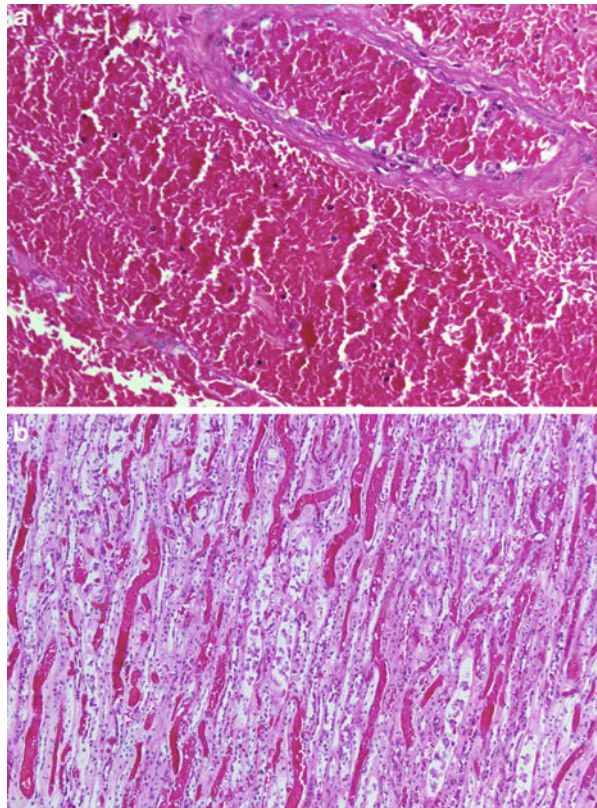
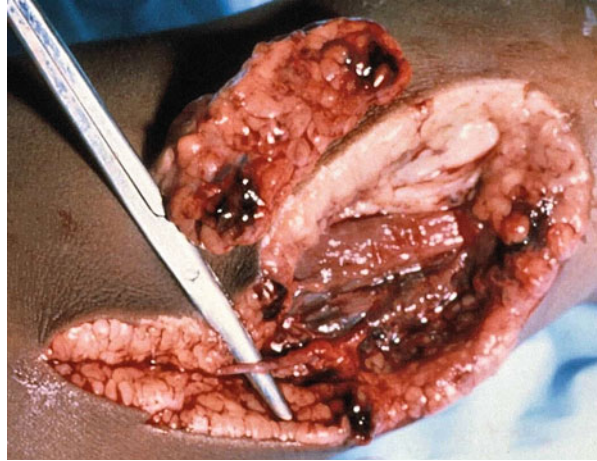


Fig. 27.25 Microscopic findings in envenomation (Hematoxylin and Eosin, H&E $\times 100$). (a) Massive hemorrhage in the soft tissue surrounding the envenomation site. (b) Renal tubules with massive DIC and myohemoglobin within renal tubules

Fig. 27.26 Postmortem ant bites. This 3-month-old infant was found deceased after a sleep period. Scene investigators were concerned with the lesions identified on her arm, raising the possibility of child abuse. The irregular and shallow erosions are typical of postmortem ant bites. These normally have a yellow base, but drying artifact can darken the lesions, suggesting a vital reaction. It is critical to correctly assess postmortem artifact from abuse and traumatic injury in any forensic investigation



Fig. 27.27 Postmortem rodent activity. Lesions from rodent postmortem predation have shallow and irregular contours and are often centered on natural orifices, such as eyes or sites of premortem injury. Note the uniform shallow contours and yellow base of this lesion, both indicative of postmortem rodent predation. Similar patterns may be seen with some aquatic predators, such as crabs in cases of drowning in crab-infested waters



well as yellow fever, West Nile virus disease, dengue fever, Rift Valley fever, and a variety of encephalitis-related diseases on every inhabited continent.

Artifacts and Postmortem Changes

A variety of animals and insects are natural scavengers in the postmortem period (Byard 2011). The disfigurement caused by postmortem predation is considerable, and care must therefore be taken to avoid confusion with premortem injury

(Figs. 27.26 and 27.27). There are striking regional differences in postmortem scavenging activity, and forensic pathologists should be aware of local scavenging patterns. Forensic pathologists and investigators should also be aware that household pets often are involved in postmortem predation (Buschmann et al. 2011).

Airway-Associated Deaths

Choking hazards are greatest in very young children due to the proclivity of infants and toddlers to place objects in their mouths, the lack of cognitive awareness of dangers in this age group, the smaller upper airway, and poorer cough reflex in very young children. In contrast with adults, where alcohol, drugs, and/or neurological impairment may be predisposing factors in airway-associated deaths, these factors are usually not a component of pediatric airway-associated fatalities. Food, coins, and balloons are the most common objects causing obstruction in children (Altkorn et al. 2008; Rimell et al. 1995). Total obstruction of the upper airway produces rapid loss of consciousness and death. Occasionally, a child is found dead without a history or suspicion of airway compromise, even in a supervised environment. Physical findings in airway-associated (“choking”) deaths may or may not include external petechiae or head and neck cyanosis; however, internal intrathoracic petechiae are usually present. The object is usually readily found within the larynx or trachea (Figs. 27.28, 27.29, and 27.30), or at the carina (Fig. 27.31). Occasionally resuscitative efforts may force the object into the proximal major bronchi. Objects smaller than the expected caliber of a child’s airway may cause death either through laryngospasm or direct obstruction of a scarred and narrowed airway. Children most at risk for airway scarring are those who had been previously intubated, particularly as a preterm neonate.

Game-Playing Asphyxia

Game-playing asphyxial deaths occur primarily in older children and young adolescents (Le and Macnab 2001; Andrew et al. 2009). Widely termed the “choking

Fig. 27.28 Airway obstruction by a balloon. This was the autopsy finding in a 5-month-old infant who was found deceased by his caregiver. The father had lain down with the infant on a quilt and both fell asleep. On awakening, the father found the infant unresponsive a few feet off the quilt. Autopsy revealed an object in the upper trachea

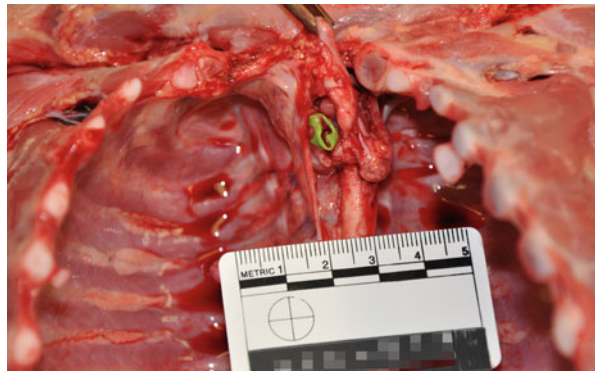


Fig. 27.29 The object recovered from the trachea was a small balloon



Fig. 27.30 Scene investigation in this airway death revealed multiple balloons and other small choking hazards on the floor where the infant was found



game” within the literature and community, this activity usually involves a form of strangulation to achieve a brief period of euphoria. Strangulation may be achieved by use of hands, ligature, or noose and may be self-administered or done by others. Rarely, a variant of chest compression produces the asphyxial state. The resulting cerebral hypoxia is reported as a “high” with light-headedness or a few seconds of unconsciousness. With release of external neck compression, a “rush” or “tingling” is described among children experiencing this activity. This activity is commonly known among preadolescents and goes by over 75 local variations in both name and activity (Centers for Disease Control and Prevention (CDC) 2010; Macnab et al. 2009) and is seen throughout the world (Noirhomme-Renard and Gosset 2011). The cases presenting to a forensic service usually involve solo-game playing and are often initially thought to be suicidal hanging deaths (Andrew and Fallon 2007). The physical findings at autopsy are similar to other strangulation or hanging deaths (Figs. 27.32 and 27.33), and the key to recognition is within the scene and death

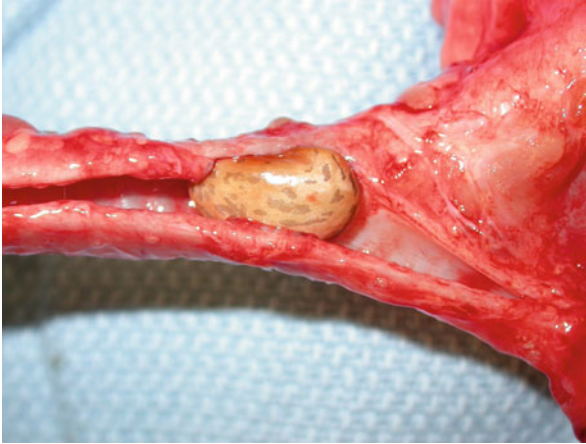
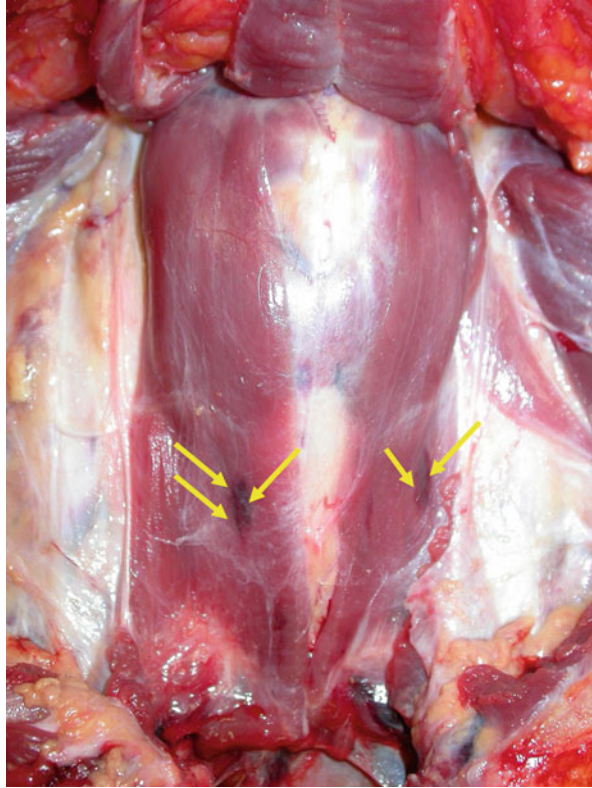


Fig. 27.31 Bean obstruction at the carina. This 8-month-old child was visiting his grandparents, crawling on the kitchen floor during a family gathering. He stopped moving and adults thought he was napping. A few minutes later, they noticed a darkening blue tone to his lips and tried to arouse him. He was unresponsive and EMS was called. He presented to the medical examiner's office as a sudden death in infancy during sleep. A sack of pinto beans had spilled in the kitchen the day before; adults thought all were cleaned up. The child had found a single bean in a floor crevice



Fig. 27.32 Neck findings in game-playing asphyxia. The pattern of ligature compression is seen at the neck. The hyperemic borders and pale center suggest the diameter or width of the constricting object. Often, a pattern may be present that corresponds to the ligature material

Fig. 27.33 Layered neck dissection in ligature hanging. Careful neck dissection after removal of the CNS and body organs may reveal hemorrhage within strap muscles of the neck, corresponding to the site of constriction



investigation (Fig. 27.34). The activity is usually hidden from adults, but is widely acknowledged among peers, who usually regard the activity as a safe, drug-free “high,” a part of thrill-seeking activity and risk-taking behavior of early adolescence. There are no indications of suicide at the scene or by history, and there is no evidence of autoerotic activity. The incident usually occurs in a private location that the child regards as safe, often within a home or school. The children are often “good kids,” without behavioral, mental health, school, or drug/alcohol use problems. There are minimal gender differences in most studies, although some studies show a male predominance. In the USA, it is more common in Hispanic and Native American/Alaskan Native populations as compared to Caucasian populations (Toblin et al. 2008). Key to recognition at the scene is the “private yet safe” location, the simplicity of the noose, absence of suspension, and facile ability to self-extricate from the compressing object (Fig. 27.34), which usually is a simple loop against which youngsters lean. There are often wear marks on hooks or furniture from previous episodes or historical incidences of syncopal episodes, voice changes, new onset headaches, abrasions on the neck, disorientation after time alone, or accessing various electronic activities (websites, blogs, chat rooms)

Fig. 27.34 Scene findings in game-playing asphyxia. This simple loop was present suspended from slats of an upper bunk. The child would lean against the loop as part of game playing; however, in this instance, unconsciousness prevented the simple action of lifting the head to remove neck constriction



for asphyxial games. The absence of suicidal ideation, depression, or farewell messages is also important to ascertain. Invariably, peers will either acknowledge similar past group or individual “game playing” or confirm that the victim sought information about game-playing asphyxia. Although some describe this as a new risk, it may be a continuum of asphyxial games of past preadolescent generations, such as “breath holding” or hyperventilation to achieve momentary alterations of consciousness. The recent deadly inclusion of ligatures and nooses greatly increases the potential for death, especially when children engage in this activity alone.

Autoerotic or sexual asphyxia deaths in children are rare and when they occur tend to be in older adolescent males (Sauvageau and Racette 2006). Key findings of autoerotic deaths are generally scene-related with sexually explicate material and/or sexual devices present, privacy of the scene, evidence of masturbatory activity, sexual fetishes, bondage or masochistic activity, and often elaborate asphyxial producing and escape mechanisms (Shields et al. 2005a, b). A review of cases from Australia and Sweden revealed no autoerotic deaths below the age of 20 and confirmed the male predominance seen in previous studies (Byard and Winskog 2012).

Disparities in Childhood Injury and Death

Accidental deaths and injuries occur in all socioeconomic, ethnic, and racial groups. However, disparities exist in the occurrence, severity, and numbers of fatalities from pediatric injuries caused by both accidental and non accidental modalities. In the USA, African-American (Brown 2010), Hispanic (Mallonee 2003), and Native American children (Goldcamp et al. 2006a; Berger et al. 2009) all have higher rates and severity of injury and death over Caucasian children, even when adjusted for socioeconomic class. Rural and frontier children are also at higher risk of injury and death during childhood as compared to their urban and suburban counterparts (Cherry et al. 2007). Forensic pathologists play an important role in correctly identifying traumatic injury and risk factors within larger communities, as well as in groups within the population they serve through a complete medical legal death investigation.

Conclusions

Accidental injury in infancy and childhood is a common, and often preventable, cause of childhood morbidity and mortality. Many of the types of injury are similar to adults; however, others have differences in incidence and character of injury that are unique to the stature and development of a child. It is imperative that forensic investigations of these deaths include information salient both to the preventability of future deaths and addressing the disparities that exist within gender, socioeconomic, and other class characteristics. Injury remains the most common cause of childhood death in most parts of the world. Prevention strategies rely in no small part on accurate assessment of the causes of death and injury in children. Forensic pathology and forensic medicine can contribute significantly in efforts to improve child safety, health, and life.

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