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Update

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Medical Evaluation of Burn Injuries

Part 1

By Barbara L. Knox, M.D. and Suzanne P. Starling, M.D.

The prosecution of childhood abusive burn cases requires special knowledge of skin anatomy and the biomechanics of burn injury. It also requires performance of a detailed scene investigation. Part 1 of this series will discuss the medical evaluation of burn injuries. Part 2 will discuss burn investigations from a medical perspective.

The incidence of childhood burns secondary to abuse has been reported from low estimates of 11%[1-8] to high estimates of 25%.[9-11] For burned children presenting to emergency departments, the frequency of abuse or neglect is reported as 19.5%.[12] Abusive burns typically occur in children younger than age six[13, 14] with most victims ranging between two to four years old.[2, 4, 5, 8, 9, 15, 16] Of the children admitted to the hospital for treatment secondary to abusive burns, infants and toddlers represent the greatest percentage of cases.[2, 6, 8, 9, 15, 17-20] Children with abusive burns require longer hospital admissions than those with accidental burns,[6, 7, 15] have increased morbidity,[6, 23] consume more resources during treatment and follow-up,[21] and are more likely to die from their injuries.[2, 6, 8, 15]

Scalding is the most frequent type of inflicted burn in childhood,[6, 16, 22, 23] with hot water immersion being the most common mechanism reported.[11, 14, 24]

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Childhood abusive burn victims are more likely to have previous or concomitant signs of abuse or neglect and previous reports to child protective services.[3, 9, 15, 19, 25-27] Most studies report that boys are more frequently victims of abusive burns.[2, 4-6, 8, 9, 14, 22, 23, 29, 30, 11, 12, 17] The ethnic composition of burned children generally mirrors that of the community.[15]

Burns primarily are classified based upon the depth of tissue injury. Historically, burn injury had been reported as first, second, third, or fourth degree injury. Most medical providers now use a classification system based upon partial or full thickness tissue injury. Superficial partial thickness burn injury results in damage to the epidermal skin layer only, and correlates with the older first-degree burn classification system. The skin is characterized by localized erythema (redness), and is analogous to a sunburn. These burns heal without treatment. Tissue damage that progresses into the dermal skin layer is reported as superficial partial thickness to deep partial thickness burn injury depending upon depth of tissue damage. These burns result in blister formation and correlate with the older second-degree burn classification. If the dermal tissue is only superficially injured, the damaged tissue will be replaced by the underlying healthy tissue. If the injury produces a deeper partial-thickness burn, these burns still can heal without scarring, as long as complicating factors such as infection are absent. When tissue damage penetrates to deeper layers of the dermis, deep partial thickness burns result and scarring occurs. Full-thickness burns cause injury through the dermis into the subcutaneous tissue layer and correspond to the older third-degree burn classification. Full-thickness burns will not heal by tissue regeneration. If very small, the lesion may heal with scar formation, however, the majority of full-thickness burn injuries require skin grafting.

Burns also are classified by the source of damage to the skin and are divided into thermal, chemical, electrical, radiation and friction/pressure tissue injury categories. Thermal burns are the most common form of accidental and non-accidental burns in children and consist of tissue damage from scalds, contact solids, flame, or radiation injury. Scald burns are further subdivided into immersion, flowing liquid, splash, and splatter injury. The majority of scald burns occur accidentally in the home environment[30] and are due to splash and spill injury by fluids other than tap water,[28] such as soups,[28] hot beverages and other cooking liquids.[29] Microwave ovens heat food and liquids unevenly and have been associated with accidental pediatric scald injury resulting from food preparation, such as in the reported case of partial and full-thickness scald burns to the mouth and throat of an infant after drinking formula heated in a microwave oven.[31]

For abusive burn injuries, scalding by immersion in hot tap water is most frequently reported.[11, 19, 28] Scald injuries account for the majority of pediatric burn hospital admissions,[16, 30, 32] and up to 14% of all scald burns are secondary to abuse.[33-36] Scald injury from hot tap water requires hospitalization in 39% of cases, and of these, 12-45% are considered to be abusive in nature.[14, 16, 33, 37, 38] Purdue et. al.[8] found that 82% of children admitted with abusive burns were scalded and of these, 83% were secondary to tap water and 59% had immersion patterns present. In contrast, only 16% of non-abused children had hot tap water scald burns. The mortality rate for abusive hot water immersion burns in Purdue's study was 10%.[8]

For suspected immersion scald injury, the pattern of injury greatly assists both the medical provider and investigators in analyzing the case for accidental versus inflicted mechanisms. Burn patterns demonstrating uniformity of burn depth suggest the child was restrained or not moving during the time of injury,[19] and bilateral (both sides of the body) burn symmetry in the absence of splash marks suggests forced immersion.[19, 24] Bilateral, symmetric lower extremity burn distribution patterns occur more frequently in abused children.[24]

Immersion burns typically present with patterned injury demonstrating uniform burn depth, sparing of the creases of the arms and legs, a clear line between the burned and unburned skin areas, and an absence of splash marks. When there is skin sparing in areas where the skin was in contact with cooler surfaces, such as sink or tub bottoms, the burn often is referred to as a doughnut burn. The presence of uniform burn line demarcation (stocking and glove injuries) suggests that a child was restrained while being immersed in the hot liquid,[39] and therefore unable to generate a splash.[14, 39] Patterned injury with skin sparing in areas of flexion suggests that the child was withdrawing from painful stimuli at the time of the injury. This latter pattern can be seen in both accidental and inflicted scald burns.

There is a paucity of information in the medical literature regarding how rapidly burn injury occurs to children's skin. Children comfortably bathe at a temperature of 101° Fahrenheit (38° Celsius).[39] Production of a deep second-degree burn to both adult and child skin requires water temperature of at least 113° F (45° C).[40-42] Both adult and child skin would require a minimum of six hours continuous contact at this temperature to induce a deep partial thickness burn.[39-42] Water temperature of 120° F (49° C) produces deep second-degree burns of the skin after 10 minutes of

contact.[14, 42, 43] Water temperatures must reach 130° F (54° C) before a difference is noted between adult and child skin burn times.[40] Children's skin is thinner, and there is an inverse relationship seen between thickness of the skin and temperature and time necessary to induce burning at this threshold. Feldman[56] reported that when temperatures exceed 130 F° (54° C), children sustain burn injury in only a quarter of the time it takes adult skin to burn.[40]

Hot water splash burn injuries typically require a minimum temperature of 140° F (60° C) in order to produce tissue injury; lower water temperatures will cool quickly and burning will not occur.[39] Scalds patterns due to splash or flowing liquid can be altered based upon the presence or absence of clothing. In addition, the type of liquid present may significantly affect the burn. Scald injuries resulting from liquids other than water, such as hot beverages, foods, grease, oils or wax, can reach temperatures much greater than the boiling point of water (212° F), and may be significantly thicker, resulting in a deeper burn due to the higher temperature and prolonged contact with the skin.[44] Pull-down splash burns typically have a "triangular" appearance with the area of greatest burn injury occurring at the area of immediate skin contact. The scalding liquid then typically causes a trickle-down drip pattern. The majority of hot oil and grease burns in the pediatric population is secondary to accidental mechanisms.[45]

Contact burns result from prolonged contact with a hot solid or smoldering source.[46] Abusive contact burns typically produce a branding injury characterized by distinct margins, grouped burn lesions, clearly inscribed patterns, and injuries on parts of the body normally covered by clothing.[47] Contact burns initially present as erythematous (red) injury with subsequent pigmentary changes as tissue healing occurs.[48] Dry contact burns include injuries resulting from objects such as curling irons, steam irons, flat irons, radiator or grill grates, cigarette lighters, or various metal kitchen utensils. Hair dryers generate temperatures of at least 110° F and retain sufficient heat within the grills to induce full thickness burns several minutes after disconnecting power.[54, 55] All of these objects leave a patterned injury on the skin in the shape of the object that burned them, often allowing an investigator to match the object to the injury.

Children frequently sustain hot iron accidental burns by touching an iron or pulling on the cord. In one study, 74% of children were supervised by an adult or older teen at the time that the burn occurred and in 34% of cases, the iron was turned off at the time of injury.[52] Iron contact burns cause approximately a quarter of all reported contact burns in children 5 years of age or younger.[53] The average age of children affected is 24 months with more than half between one and two years of age. The primary site of the injury in more than 60% of the children is the hands. The pattern left on the skin by iron burns can help in differentiating accidental from abusive injury mechanisms. If the burn pattern demonstrates a smeared edge appearance suggesting that the child was attempting to flee from the iron, an accidental mechanism may be more likely.[39]

Cigarette burn injury in children can result from accidental contact with the glowing tip of a cigarette or from deliberately inflicted injury. Brush-by contact with heated cigarette ashes results in a poorly defined oval or wedge-shaped lesions[56] and typically occur in areas not covered by clothing. These accidental burns rarely result in full-thickness skin injury because the child quickly withdraws from the painful stimulus. Cigarette burns caused by abuse usually are multiple grouped lesions on the hands and feet.[57] An inflicted cigarette burn produces a deep partial to full-thickness burn lesion that ranges from five to 10 mm in circumference and has a sharply defined punched out appearance.[56] If the cigarette contacts the skin for more than one second, blistering can develop.[56] If untreated, the lesion heals gradually, resulting in a wrinkled appearing scar.[56] Cigarette burns frequently are confused with infectious skin conditions.

Accidental foot burns in children during summer months resulting from contact with heated pavements are very common. Burns due to contact with naturally heated surfaces are more likely to be bilateral, superficial partial burns primarily of the sole of the foot.[49, 50] Partial thickness burns from car seats also have been reported to mimic inflicted abusive injury.[51]

Chemical burns resulting from caustic ingestions can be accidental, the result of neglectful child supervision, or intentional. Chemical injuries can result in deep burns since the chemical may continue to burn until properly removed from the skin. Alkali burns (such as lye) are associated with deeper and more extensive burns than acids.[58] Adult drug use is a risk factor for pediatric caustic ingestions. Children have been reported with significant mouth and throat burns after ingesting chemicals used in the production of methamphetamine and liquids (ammonia and potassium hydroxide) used in the preparation of free-based crack cocaine. [59,60] Burns also have been reported with concentrated bleach. Bleach does not immediately produce pain and therefore causes skin lesions that develop slowly and worsen with prolonged contact. Splash marks might be absent with black

burns.[61]

Laxative-induced rash of the buttocks frequently is confused with abusive immersion burns. The active ingredient, senna, in products such as Ex-Lax produces diarrhea in cases of childhood overdose, leading to erythema and blister formation on the buttocks after prolonged exposure.[62]

Flame burn injury in the pediatric population most often is secondary to house fires. The leading cause of death from pediatric burns is from house fires. Abusive flame burn injury secondary to holding a child's skin in contact with flame or to ignition of clothing also occurs. Approximately 10% of abusive pediatric burn admissions are caused by fire or flame. [6,8]

Electrical burns in children represent approximately two to three % of all burns that require treatment in the emergency room.[63] The majority of all pediatric electrical burn injuries occur within the home setting,[63-65] and involve children less than five years old.[66] Children typically sustain localized burns when injured by electrical current,[65-67] most commonly from biting an electrical cord or placing an object into an electrical outlet.[63, 64] Though most reported electrical injuries are not due to deliberate acts of child abuse, many typically occur in unattended or poorly supervised children. Electrical burns inflicted by a stun gun result in 0.5 cm hypopigmented paired lesions.[68] Although not strictly electrical in nature, children also have sustained full-thickness burns resulting from being placed in microwave ovens.[69]

There are multiple conditions that mimic burns, and a qualified medical provider should evaluate individual cases for these mimic conditions. Innocent pressure injuries from constricting clothing can be confused with dry contact burns.[48, 70] Infectious processes can mimic scald burns and cultural medicine practices can mimic contact burns. Practices including cupping, maquas, coining, and moxibustion have all been cited as mimicking burns. Although not considered abusive, in the United States when children sustain burns secondary to cultural practices, the family should be strongly discouraged from continuing use of folk medicine therapies for the child.

Child abuse by burning can occur in numerous ways, resulting in various burn patterns and severity. It can be caused both by infliction of injury and by neglect due to a lack of adequate supervision.[71] A thorough medical evaluation can help distinguish inflicted from accidental burns, help determine the mechanism of injury and is invaluable in the investigation and prosecution of child abuse by burning.

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Burn Investigations-A Medical Perspective

Part 2

A THOROUGH MEDICAL EVALUATION is essential in the investigation and prosecution of abusive burns. When a child presents for medical care, the physician should perform a thorough physical examination noting the type of burn injury, severity of injury, and presence of other physical examination findings suggestive of abuse. Separate histories should be obtained from the verbal child and caregiver regarding causation and time of the injury. The interviews should be conducted as soon as possible after presentation with a burn injury[1] and concise documentation of the initial history of events is important since the perpetrator's account of events may change over time.

If the burn source was secondary to hot water, the medical provider should inquire about the setting of the water heater temperature and temperature of the water coming from the tap. It is also important to inquire about how long the child was in contact with the source of the burn and how the child gained access to the source.[2] Witnesses to the injury also should be sought, since many cases of pediatric burn injuries are the result of poor caretaker supervision. Information regarding the presence of existing medical conditions such as neurologic, cognitive, or genetic disorders which can impair the child's ability to perceive pain or alter the child's level of consciousness also should be collected.[3] Handicapped children are at a higher risk of tap water burns secondary to impaired sensory and motor capabilities.[4]

Clark et al[5] evaluated the use of a screening profile to enhance recognition of suspicious pediatric burn cases. Burns

with a history that is developmentally incompatible for the child, history of prior accidents involving the child, differing histories for the event, history incompatible with the physical findings, burns attributed to siblings, inappropriate parent affect, presence of other injuries, and mirror image burns were all correlated with inflicted injury.[5] Abusive pediatric burns occur more commonly in families with a single, young, socially isolated parent from a lower socioeconomic class [6-16] Children abused by scald or thermal contact burns are most likely to come from impoverished welfare dependent homes.[17] The abusive perpetrator is most frequently the child's parent or the mother's boyfriend.[14] Showers[12] found that women are the most frequent perpetrators in abusive childhood burn cases, contrasting Ojo et al[7] who documented all male perpetrators, identified as the biologic mothers' boyfriends.[7]

After completing a detailed history, the medical provider should perform a more detailed physical examination of the child focusing on evaluating the patient for other signs of trauma, cutaneous findings or evidence of neglect such as malnutrition, failure to thrive, or poor hygiene. The provider should specifically document the location of the burn(s), depth of tissue injury, burn contours and percent total body surface area affected by the burn.[2] Burn diagrams should be used in conjunction with photo documentation of the injury. The medical provider should document the child's height and weight on admission, and plot this information on an age-appropriate growth curve. When possible, these data points should be compared with previously obtained height/weight data to evaluate for poor weight gain or abrupt weight loss, which might indicate a malnourished state. A developmental examination also should be performed in order to determine if the child's developmental state is consistent with the reported causation of injury.

Using the history of the burn injury compared to the medical examination findings, the medical provider will determine if there are indications of abusive injury. Inconsistent history, social situation deemed as placing the child at risk, concerning pattern of injury, or extreme magnitude of injury when compared with the stated history are all concerning for child abuse.

Due to the forensic issues surrounding cases of pediatric abusive burn injury, detailed medical documentation is important. The medical provider should inquire about and document a detailed account of the history including specifics regarding statements by the child or caregiver of burn location, description of the environment in which the burn occurred, and temperature (if available) of the burn source. It is also important for the medical provider to document any clothing that the child may have been wearing during the time of the injury. Not only should the location of burn injury be clearly described, with inclusion of body diagram drawings, but it is also important to document areas that are free of injury. Photographs of burns are important to document visual evidence of the injury. All burned and non-burned areas should be photographed with a photo ruler in place to accurately assess burn size.

There are no studies documenting physician accuracy for dating burn injuries. However, physicians experienced in burns and wound healing often can assess the timing of a burn. In cases where burns are of varying ages, medical providers should be able to state that one injury is older than another based upon differences noted in wound healing between the lesions. Documenting that one burn injury is older than another would refute a caregiver's statement that the injury was secondary to an accidental mechanism occurring during a single event.

Medical providers frequently question the necessity for obtaining a skeletal survey in children presenting with burn injury in the absence of other traumatic findings. In 1983, Merten et. al.[18] documented that children two years of age and younger with physical injury (including burn injury) were at greatest risk of occult fracture and that 77% of occult fractures occurred in this age group. In 2007, Hicks and Stofli[19] evaluated the frequency of occult fractures in children with suspicious burns compared to children with other forms of physical abusive injury. The study documented 14% of pediatric burn cases had fractures on skeletal survey compared to 34% of children in a non-burned abused group. This study concluded that though children with abusive burns have a lower frequency of occult fractures than children with other physical abuse injuries, the 14% incidence of occult fractures supports routine imaging in this age group. A subsequent study found 16% of children presenting with burns also had fractures, and that for children under 24 months of age, 19% were fractured.[20] This work further supports the need for skeletal survey imaging in children less than two with suspicious burns.

All suspicious burn injuries should be investigated by individuals experienced with scene assessment and evidence collection. Most burn scene investigations are conducted by trained law enforcement personnel or child protective services workers. In cases of hot water scald burn injury, a detailed scene investigation is necessary to assist with the critical analysis of the injury by a multidisciplinary team. Investigators should take a thermometer, tape measure, timer

or stop watch, and camera equipment to the injury scene. A scientific thermometer designed to measure liquids and calibrated for accuracy should be used during these investigations. These thermometers typically can be purchased through a scientific catalogue or via the Internet. Most store-bought thermometers are not significantly accurate for forensic purposes. Thermometers that do not specifically measure liquids, such as meat thermometers, are inaccurate and should be avoided in burn scene investigations. Even scientific thermometers can lose accuracy over time and need to be recalibrated.

Prior to arrival at the scene, investigators should discuss the case with medical providers in order to determine the suspected mechanism of injury, which will help guide the investigation. In cases of suspected hot liquid burns, the investigators should record the water heater temperature. In the United States, most homes are heated with either an electric or gas water heater. If the scene has an electric water heater present, investigators need to examine and document the water temperature recordings from both the upper and lower water heater thermostats. The upper thermostat functions to heat only the top-most layer of water for replacement of water that has been drawn off. The lower thermostat functions to maintain a constant water temperature within the heating reservoir. To avoid electrocution, investigators must disconnect the power source to the electric water heater prior to investigation.[3] If the scene has a gas water heater, the thermostat is typically located on the outside near the base of the water heater unit.

Investigators should obtain a history from the caregiver regarding reported water usage in the time period preceding the injury. This information can be analyzed to determine if the burn injury occurred at a time when the water heater was at a constant temperature, or if the injury occurred during a time when the water heater was re-heating following repeated withdrawal of hot water from the unit. For hot-water burn injury occurring in an apartment complex or other area containing a central water heater source, it is important to determine if the water was mixing with another water heater, thereby potentially altering water temperature in relation to water heater temperature recordings. Information regarding scene location in relation to the water line also should be documented. Gas heaters have the potential to undergo water heater stacking, a phenomenon where the water may super-heat after multiple small amounts of water have been removed in short succession.

The entire room in which the burn injury reportedly occurred should be photo-documented. Sinks and tubs should be measured, including width, height, length, inside depth, and construction material (porcelain, fiberglass, metal) and the distance from the basin to the faucet.

Investigators should clearly document the hot running water temperature at multiple time intervals including initial temperature, peak water temperature reached, and seconds required to reach this peak measurement. Note if the water is free flowing, or if the drain is plugged to some degree, thereby causing water to pool. Water should be collected in the tub or sink to the depth that is reported by history or documented on the physical examination. Temperature measurements from the collected water and the water fill rates should be documented.

Immersion burn injury patterns can be reconstructed using dolls. Additionally, the use of a fabric dye in water may be helpful.[3] Simulating the burn mechanism using the dyed water will leave dye on the skin in a pattern which could reflect the child's injury.

All information should be analyzed to correlate the child's burn injury with the caregiver's stated mechanism of injury (if available), developmental level of the child, size, and child's ability to turn on or adjust the water faucets. For non-water burn injuries, scene investigation can provide the potential object causing the injury. Patterned objects can be collected to compare to the burn site. Such items as irons, curling irons, and metal objects can be presented to the medical provider to compare to the burn. Scene investigation also can identify unsafe and potentially neglectful situations which might have contributed to the injury or predispose the child to further injury.

The literature has identified many factors that can help a multidisciplinary team determine if a burn injury is accidental or inflicted. Literature supports that a history of prior accidents, history incompatible with the physical examination findings, burns inconsistent with the developmental level of the child, differing or inconsistent historical accounts of the injury, inappropriate parental affect, and a delay in seeking care are concerning for abusive burn injury. In addition, certain patterns of injury, burns localized to the genitalia, perineum, buttocks, and both lower or upper extremities, presence of additional injuries, and older injuries are all reported frequently in inflicted injury.

When presented with a suspicious burn, review of the injury using a multidisciplinary team is best practice to ensure thorough investigation, critical analysis, and accurate diagnosis of the case. Collaboration between the investigative team and the medical professionals is a very important tool in the effective prosecution of a case of inflicted burns.

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