CHAPTER 2

Fire Environments and Characteristic Burn Patterns of Human Remains from Four Common Types of Fatal Fire Scenes

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2.1 Introduction

Heat-related damage that is observed on burnt bodies from fatal fire scenes results from combinations of heat, duration, and, in many cases, the type of environment in which the fire occurred. The sequence of heat-related damage resembles the stages of decomposition, since soft tissue breakdown also occurs along a continuum that is affected by temperature, duration, and environment (Ubelaker, 1997). These same variables influence the physical condition of the burned body from a fatal fire scene. Thermal damage occurs rapidly over minutes to produce the physical characteristics that investigators observe at the scene and / or during the post-mortem examination at the Medical Examiner / Coroner's Office. The fire environment plays an important role in the creation of burn characteristics to the body's layered soft tissues of skin, subcutaneous fat, layered muscles, internal organs, bones, and dentition. This chapter introduces the importance of correlating the findings of the scene with burn pattern characteristics that can result from four common types of fatal fire scenes: structures, vehicles, confined space, and open space. Examples of each type of scene are presented, showing the full spectrum of heat-related damage that occurs to the body's layered tissues from start to finish through progressive diagrams with stages of thermal damage that occurs over time to the victim's body within the fire environment. Examples are given for what is expected to survive of the body after a devastating fire; the final burned condition of remains; and where / how to search for possible fragmentary bones within fire debris for each scene type. In addition to the normal heat-related changes that occur during the fire, examples of common

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post-fire fragmentation are also presented to help anthropologists distinguish fractures between the two post-mortem events.

2.2 Experimental Research of Fire and Human Bodies

The results presented in this chapter originated from over 12 years of experimental field observations (starting in 2008) from burning non-embalmed human cadaver bodies (n = 150+) in a variety of fire environments (n = 69 structures, n = 36 vehicles, n = 24 confined space, and n = 23 for outdoor scenes) to explore differences and similarities of burn patterns. This research was conducted with the San Luis Obispo Fire Investigation Strike Team (SLO FIST) during the annual Fatal Fire Death Investigation Course in San Luis Obispo, California (www.slofist.org). Non-embalmed cadaver bodies are placed into mock crime scenes (burn cells with fully furnished rooms, vehicles, trailers, outdoor brush piles, burn barrels, etc.), ignited, and then documented with digital photography, and thermocouples for temperatures during the fire, followed by post-fire photography and documentation of the burned body's final condition.

2.3 How the Human Body Burns

Fire and heat progressively alter the appearance and condition of the body's layered tissues, along with other combustible materials / fuels (furnishings) in the vicinity (Icove and DeHaan, 2009; DeHaan & Icove, 2012). Exposure to heat (direct / radiant) causes the body's soft tissues, primarily the skin surfaces to shrink and distort within minutes. Tissues of the body burn sequentially as layers of skin, subcutaneous fat, skeletal muscles, internal organs, bone and dentition (Adelson, 1954; DeHaan *et al.*, 1999; DeHaan and Icove, 2012; DeHaan and Nurbakhsh, 2001; Dolinak *et al.*, 2005; Fairgrieve, 2008; Icove and DeHaan 2009; Pope, 2007; Pope *et al.*, 2022; Spitz, 2006). Heat causes the charred skin surfaces to shrink and split into tapered ovoid openings which exposes the underlying subcutaneous fat layers (Adelson, 1954; Dolinak *et al.*, 2005; Fairgrieve, 2008; Pope *et al.*, 2022; Spitz, 2006; Pope, 2007). The underlying layer of subcutaneous fat renders from heat exposure into a liquefied grease that becomes a contributing fuel source during the fire (DeHaan *et al.*, 1999; DeHaan and Nurbakhsh, 2001). Rendered subcutaneous fat collects and pools at the body / floor junction, where it becomes absorbed and wicked into charred clothing and fire debris at the floor surface (DeHaan *et al.*, 1999; DeHaan and Nurbakhsh, 2001; Icove and DeHaan, 2009; DeHaan and Icove, 2012). Pooling and spattered grease are responsible for the spread of a rendered subcutaneous fat-fueled fire that can sustain flames burning around the body that can last for hours (DeHaan *et al.*, 1999; DeHaan and Nurbakhsh, 2001; Icove and DeHaan, 2009; DeHaan and Icove, 2012). The presence of clothing on the victim's body is an important variable since it protects the underlying skin surfaces from open flames that burn above in the fabrics during the early stages of the fire. Later as the charred clothing materials burn away and expose the underlying skin surfaces, the charred fabrics at the body-floor junction are ideal wicking materials for absorbing and burning the body's rendered subcutaneous fat as a contributing fuel source for the duration of the fire.

Under the subcutaneous fat layer are dense and fibrous muscle layers, which are a poor fuel source, that surrounds and protects the inner skeletal structures. Heat exposure causes the muscle fibers to shrink and contract, which initiates limb flexion and body movement during the fire that is commonly known as the pugilistic posture. Sites of early bone exposure correspond to thinner areas of overlying skin and soft tissues that stretch over these flexed joints. During the fire, the upper extremity exhibits heat-related burn patterns with exposed bone surfaces that occurs earliest on the dorsal surfaces of the flexed phalanges, metacarpals, carpals, and distal radius and ulna of the flexed hand and wrist, followed by exposure of the proximal ulna and distal humerus of the flexed elbow joint, followed by posterior and lateral exposure of the humeral midshaft, and lastly the lateral surfaces of the proximal humerus at the flexed shoulder joint (Pope *et al.*, 2022; Pope, 2007). Sites of early bone surface exposure for the lower extremity can include the dorsal surfaces of the flexed phalanges, metatarsals, tarsals (without footwear), anterior surfaces of the tibia midshaft, followed by exposure of the proximal tibia, patella, and distal femur of the flexed knee, then the anterior / lateral surfaces of the femoral midshaft, and lastly exposure of the lateral surfaces of the proximal femur at the flexed hip (Pope *et al.*, 2022; Pope, 2007). Pugilistic postural changes are best observed in the extremities but also occur for the torso, which results in an arched spine of the neck and lower back (Adelson 1954; Dolinak *et al.*, 2005; Icove and DeHaan, 2009; Pope *et al.*, 2022; Pope, 2007; Pope *et al.*, 2004; Spitz, 2006; Ubelaker 1997; Ubelaker, 2009; Spitz 2006). Upper limb repositioning causes the flexed arms to move outwardly above the floor / ground surface and then extending over the chest. Positional changes for the lower limb results in the spreading apart of the upper legs at the hip with outwardly flexed knees with the lower legs and heels drawn together at the ankles near the midline, and with the arched foot and ankle pointing downward (Pope *et al.*, 2022; Pope 2007). Longer durations of heat exposure results in the greater degrees of repositioning and flexion of the extremities for the observed pugilistic posture. Longer durations of burning can result in reduced charred muscle mass which can result in greater flexion of the joints and with increased exposure of the burned bone surfaces (Figure 2.1). Heat-related color changes of burned bones (charred and calcined) results from surfaces that were exposed the earliest and the longest to heat (Bohnert *et al.*, 1998; Pope *et al.*, 2022; Pope 2007).

Bone exposure was first observed over flexed joints of the extremities that resulted from skin splits and from the shrinking / retracting musculature. Once exposed directly to heat, the bone surfaces undergo patterned heat-related color changes. Heat exposure produces a sequence of color changes that results from

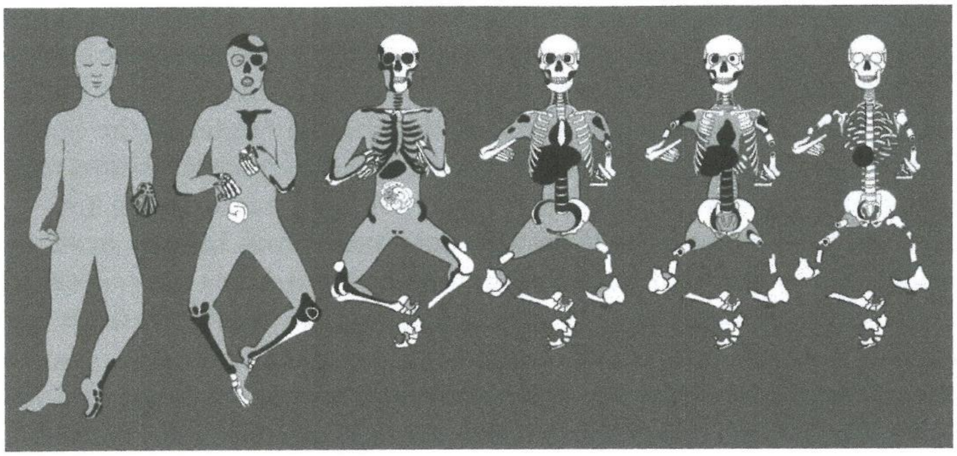

Figure 2.1 The sequence of the pugilistic posture, progression of burn damage, and sites of bone exposure to heat.

the gradual pyrolysis of the organic components from the bone's surface. The heat-related color changes are transient on the exposed bone surfaces during the fire which can result from skin splits over the flexed joints (fingers / wrist / elbow) or from the gradual retraction of charred musculature along surfaces of the bone. The continuum of heat-related color and texture changes begins with the exposure of the unburned light yellow bone that transitions into a thin fluid white / brown linear heat border that contours the charred muscles, next follows the development of a progressively darker band of greasy translucent tan / yellow / brown bone that borders the greasy black charred bone, and later can later transition into the brittle dried white / gray calcined bone from prolonged heat exposure. (Bradtmiller and Buikstra, 1984; Shipman *et al.*, 1984; Buikstra and Swegel, 1989; Goncalves *et al.*, 2015; Mayne, 1990; Mayne Correia, 1997; 2009; Pope *et al.*, 2004; Pope, 2007; Pope *et al.*, 2022; Thompson, 2004; Ubelaker, 1997). Exposed charred and especially calcined bone surfaces can develop heat-related fractures from shrinking of the cortical surfaces. Brittle charred and calcined bone becomes fragile and thermally weakened during the fire, which can break away under minimal pressure and may become separated from the main body and fall below into the fire debris substrate both during and after the fire (Pope *et al.*, 2022; Pope, 2007). Another common heat-related change is the fracture and separation / disarticulation of the flexed hand and wrist from the charred distal radius and ulna and may be referred to as 'fire amputation' of the extremities. Heat exposure causes the bulkier flexor muscles and tendons of the forearm to shorten which produces tension in the thermally weakened burned bone on the posterior surfaces of the distal radius and ulna that can fracture under strain. After the burned hand and wrist break away, they remain attached with the shrinking musculature and travel along the forearm. Separation of the burned hand and wrist can occur from heat-related fractures through the distal forearm bones or may occur along the natural joint surfaces above the wrist. Similar heat-related fractures can occur to the lower leg and ankle from the cumulative strain of the shortened lower leg (calf) muscles and Achilles tendon that stress and break the thermally weakened distal tibia and fibula, or may result in the separation of the foot and ankle along the natural joint surfaces. Later, when most of the long bones of the extremities have been exposed as charred and calcined structures, then they can become prone to fragmentation from the body during later the stages of partial to full cremation. This was observed in the distal ends of burned long bones that had fractured away from the body from the weight of the heavier charred musculature remaining around the flexed joints. These fractured segments of the extremities in charred and calcined bones occurred around sites of the distal radius and ulna, distal humerus, distal tibia and fibula, and distal femur. An understanding of how and where these burned skeletal fragments and dentition should be located and distributed can result in a more complete search and recovery of the burned human remains from the fatal fire scene.

2.4 Variables of Fire Environments

Fire environments are dynamic, with turbulent flames and fluctuations in temperatures (Icove *et al.*, 2009; DeHaan and Icove, 2012), unlike the artificial fire environments of crematoriums or muffle furnaces that have been traditionally used to model burnt human bone. Progressive changes in the fire's size begins first with ignition, followed by the stages of incipient growth, growth, fully developed / flashover, decay, followed by intentional / natural extinguishment (Icove and DeHaan, 2009; DeHaan and Icove, 2012). The duration of the fire correlates with the available fuel sources that burned around the body and the resulting extent of heat-related damage to the layered tissues of the body that burned within the surrounding fire environment (Bohnert *et al.*, 1998; Gonçalves *et al.*, 2015; DeHaan and Icove, 2012; Icove and DeHaan 2009; Pope *et al.*, 2004; Pope *et al.*, 2022).

Combustible fuels surrounding the body can also impact the degree of burn damage to the victim's body (Icove and DeHaan, 2009; DeHaan and Icove, 2012). These combustible fuels can include: natural materials such as wood, fibers, and fabrics; synthetic materials such as plastics, PVC, foam, and upholstery; and non-combustible materials such as metal, glass, ceramics, concrete / stone, drywall / gypsum board, and insulation (Icove and DeHaan, 2009; DeHaan and Icove, 2012). Any combination of these combustible materials and fuels may be encountered in common residential structural and some within vehicular fires. In addition to their spatial relationships with the body before, during, and after the fire, these burning materials can influence the body's degree of final pugilistic posturing and the heat-related burn patterns to soft tissues and bone. For example, a body that was originally lying on a couch surface can later fall to the floor as the the thermally weakened and charred wooden framework collapses under the weight of the victim's body – and if burning continues with heavy fire damage to the floor, the body may potentially fall through the living room floor and into the lower levels of a basement / crawl space. While burning on each item or surface, the body undergoes normal heat-related tissue changes of the layered soft tissues and bone along with positional changes in the body with flexion of the limbs. However, alterations can arise when the body makes contact with new objects / surfaces (such as fire debris on the floor) or later becomes partially protected / restricted by fire debris (ex: a structural beam or roof tiles falling on the body). Partial burial within fire debris also protects those surfaces from direct flame impingement. DeHaan (2008), outlined variables of fire exposure to human remains: (1) Size of the fire (a) Single item burning, (b) Multiple items burning, (c) Full-room involvement (flashover), (d) Sustained post-flashover burning. (2) Exposure of the body (a) On combustible floor for duration of fire, (b) On top of burning item(s), (c) On combustible floor that collapses during fire, (d) In suspension on a metal "framework" (e.g. car seat), (e) Exposed to fire on all sides. Most of these and other variables will be presented for the four common types of fatal fire scenes and the resulting burn patterns to the body.

2.5 Structure Fires

Residential structure fires begin as enclosed spaces that can involve variables of combustible and non-combustible furnishings; interior square footage of rooms; overall structure (manufactured home vs. a 2 story house), interior dimensions and layout (living room, hallways, bedrooms); the presence, number, and size of openings for ventilation (windows, doors); and the availability of various combustible construction materials (Icove and DeHaan, 2009; DeHaan and Icove, 2012). Common combustible furnishings in a residential structure fire can include beds, chairs, couches, recliners, or loveseats. These furnishings, in addition to other combustible fuels in the room (fabrics, wooden tables, cabinets, desks, dressers, etc.), can also contribute to the fire's growth and development around the body. Common household furnishings may be located under the body (couch / bed / recliner), next to the body (dresser / table / chairs), or have fallen on top of the body (bookshelf / cabinets) as fallen fire debris. Within a residential fire, the body can burn differently in various situations: burning directly on the floor, on furnishings (bed / recliner / couch), supported / suspended by floor joists under burned out floors, or falling through a thermally compromised floor into a lower level (basement or crawlspace) in and surrounded or partially buried in deeper fire debris layers. Partial or complete burial within layers of fire debris, (especially under burned gypsum board from collapsed walls and ceiling) not only protects those surfaces from direct flame impingement but also desiccates and dehydrates the charred muscle fibers on the burned surfaces, which can result in better preservation of the victim's body within the fatal fire scene, even when the fire damage to the structure is considered a total loss. Examples of each variable of the different fire environments are provided below, along with discussions of variables' influence on characteristic burn patterns to the layered soft tissues and heat-related burn patterns of exposed skeletal elements and dentition, the body's final burned condition, and when present, where the burned bone fragments may be distributed within the fire debris during the search and recovery for more heavily damaged burned bodies.

2.6 Burning Directly on the Floor

A body lying on a floor surface, from collapse or as their original position, burns distinctively. Any surface of the skin (face-up, face-down, or on the side) that are in direct contact with the floor remains protected from direct flame impingement, while the exposed surfaces of the layered soft tissues can burn from radiant / direct heat (Figure 2.2). Tight fitting clothing, belts, bras, and footwear that are in direct contact with the skin can delay burning of those protected areas until they become thermally compromised and burn away. During growth and development of the fire there is a continuum of heat-related changes that can occur to the layered soft tissues of skin, subcutaneous fat, layered muscles, organs, and exposed bone surfaces along with flexion of the extremities into the pugilistic posture are common heat-related transformations that can occur during burning. However, when the surrounding combustible fuels have been expended or extinguished, this arrests the heat-related changes to the body. When the victim is directly in contact with a solid floor surface of wood, tile, carpeted / tiled, or concrete slab, it protects and preserves that area of the body, which may include facial features, tattos, scars, or personal effects. Structure fires that burn for longer durations can result in deeper thermal damage to the layered soft tissues and bones of the victim's body. Burned shrunken and retracted muscles expose the once protected bone surfaces, directly to heat that undergoes thermal color changes until the fire is extinguished. Bodies with heavy fire damage and exposed burned bone surfaces may incur fragmentation during and / or after the fire which can result in smaller pieces distributed on the floor within the fire debris around and / or on the charred body (phalanges).

2.7 The Body on Furnishings: Couches and Chairs

Couches, recliners, and loveseats share a similar construction of a basic wooden framework with metal components of S-springs and / or metallic wires and hardware, foam cushioning, fabrics, and upholstery. Initially, the body remains elevated above the floor by the cushions and framework. As the fabrics and foam cushions burn away, portions of the underlying wooden

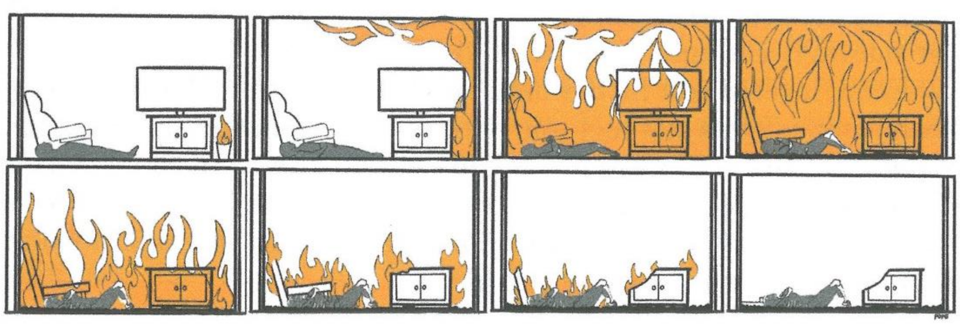

Figure 2.2 The sequence of heat-related changes of a body burning on the floor.

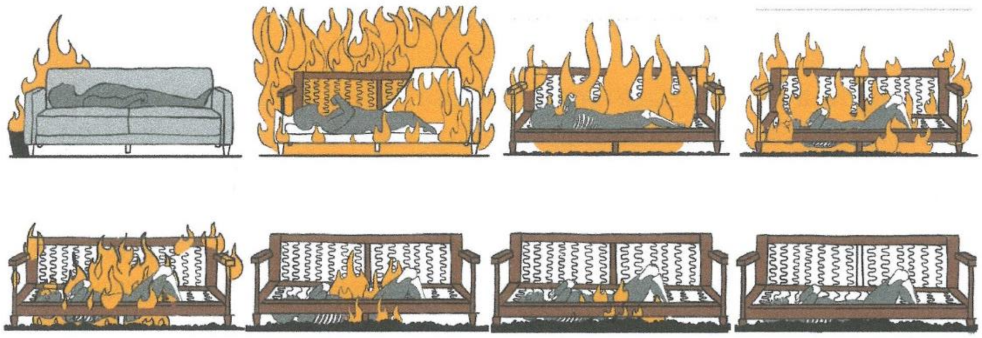

Figure 2.3 The sequence of heat-related changes of a body burning on a couch.

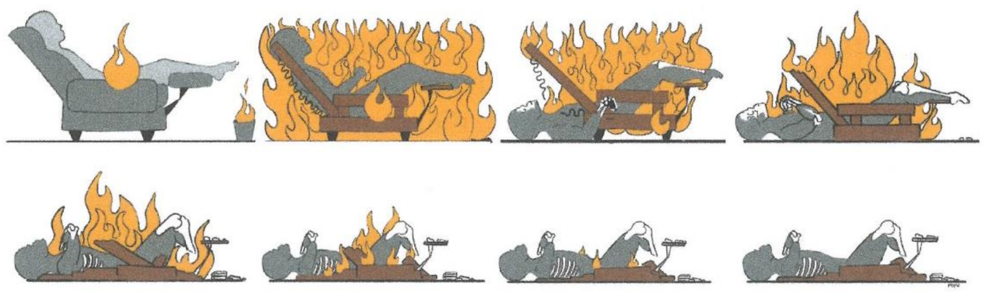

Figure 2.4 The sequence of heat-related changes of a body burning on a recliner.

framework becomes exposed directly to the fire. Surfaces of the body that are in direct contact with the fabrics / upholstery will initially remain protected from direct flame impingement, while the exposed surfaces will undergo heat-related changes to the layered soft tissues, bones, and the pugilistic positioning of the flexed extremities. As the flammable fabrics and cushion materials burn, the underlying wooden framework becomes exposed to flames and thermally weakened. The body sags and sinks into the burned wooden framework, from thermal fatigue of the metal S-springs sagging under the weight of the victim's body. (Figures 2.3 and 2.4). The weight of the body is then lowered to the floor surface into the fire debris layer which results in protection of those underlying surfaces from direct flame impingement. Victims that are seated in a thermally compromised recliner can collapse with the upper body extended through the charred seat back framework onto the floor. Bodies that were seated in basic wood or metal chairs (such as at a kitchen table) may slump over or sideways and may collapse onto the floor. For longer durations after flashover, the layered soft tissues of the body can continue burning from rendered subcutaneous fat as a fuel source that sustains smaller flames burning at the body-floor junction and can remain concentrated around the torso and upper thighs. After the fire, any burnt bone fragments that had fractured away from the body and fallen into the fire debris are likely to be found surrounding the body on the floor within the fire debris.

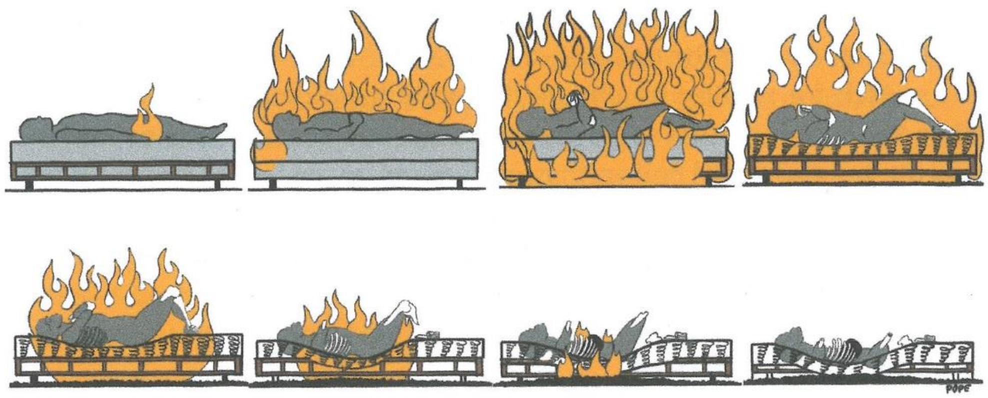

Figure 2.5 The sequence of heat-related changes of a body burning on a bed.

2.8 The Body on Furnishings: Bed

The structure of a bed (mattress and box springs) differs from the basic wood framework of couches and chairs. Mattresses that are constructed with uniform inner metal coil springs (not memory foam) keeps the body elevated and suspended above the floor during the fire. Surfaces of the body that are in direct contact with the bedding and mattress materials remain protected, while the exposed surfaces can become thermally damaged by flames and heat. As the flammable bedding fabrics and mattress materials burn away, the internal metal coil springs become exposed and supports the weight of the body for longer durations than the wooden frameworks of couches and recliners (Figure 2.5). The metal coil springs keep the body elevated within the fire environment and allows for more evenly distributed circulation of heat and flames that surround more surfaces of the body, which can result in more extensive burn damage to areas of layered soft tissues and exposed bone surfaces. The increased circulation of heat and flames around more / all surfaces of the body results in more evenly distributed burn patterns. Suspension of the body on top of the metal coil springs also results in rendered subcutaneous fat that drips below into the fire debris layer directly under the body that sustains a fuel source for open flames that burns both under the body and on the carbonized tissues of the decedent.

The annealed sagging metal coil springs (mattress / box springs) can cause the body's weight to shift position during the fire and this is also influenced by movements of the limbs and body from changes in the pugilistic posture. In some cases, the body may roll off bed and onto the floor during the fire. Exposed and burnt bones (charred and calcined ribs, phalanges, or cranial / long bones) may break away as the body moves and changes its position on the sagging burned mattress springs. Larger and more recognizable sections of the body often remain suspended during the fire, while the smaller burned bone fragments (charred and calcined portions of the fingers, hand, wrist, ribs, and / or cranial bones) can fall through the exposed metal springs and into the underlying fire debris. After the fire is extinguished, the search for burned human remains should include the identification of the larger recognizable portions of the body resting on top of the bedsprings followed by the careful hand an excavation and dry screening of the fire debris located under the mattress springs and the remaining burned bed framework to search for smaller fragments that may have detached and fallen during and after the fire event. In some cases, the carbonized soft tissues may become fused to the burned metal coil springs, which can make body removal more challenging and may produce additional post-fire fragmentation to the fragile burned bones during the manual separation and recovery process of the victim.

2.9 Loss of the Floor

Post-flashover conditions may result in the partial to total loss of walls, ceiling / roof materials, and, later may occur to thermally compromised areas of the floor. Burnt residential structures that have a lower-level crawl space or basement under the main house / manufactured home or that are multistory dwellings require extra considerations for the search and recovery process after a devastating fire. The potential for a thermally and structurally compromised floor around and under the body can introduce a new variable to the burning process, which can result in changes of the body's position, the extent of burn damage, and burn patterns to the body (Figure 2.6). Depending on the structure (single-story house, multistory house, apartments, or manufactured home, basement, crawl space the added variable of portions of the floor burning away is important to consider during the search and recovery process).

Wood floors (bare or carpeted) that burns from the surrounding fire environment later can become fueled by rendered subcutaneous fat that becomes absorbed and burns in the underlying charred wood surfaces. In more extreme cases, when areas of the floor have been breached by flames, these openings can allow for additional heat circulation and open flames around more surfaces of the body,

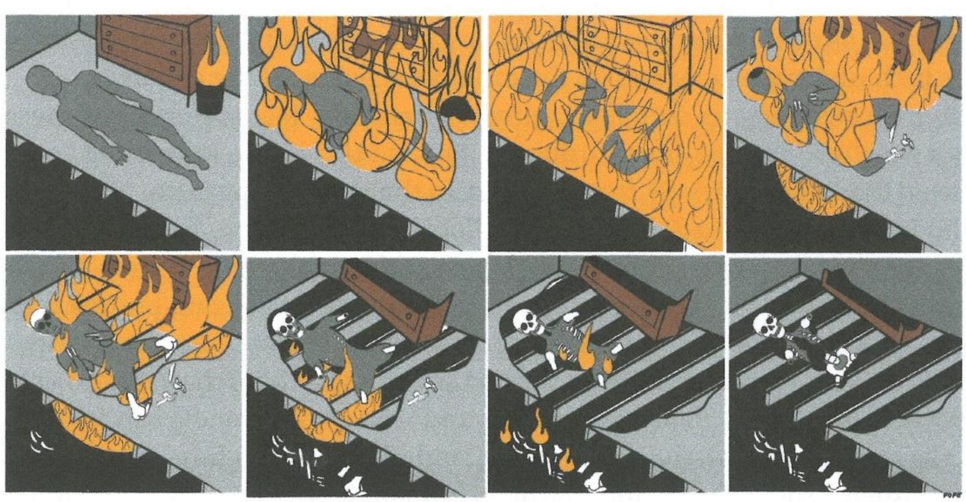

Figure 2.6 The sequence of heat-related changes of a body burning on floor joists.

especially if the victim is partially suspended and supported by the underlying floor joists and structural support beams. If portions of the burnt floor collapse, surfaces of the body may rest on the underlying floor joists / structural beams. The spacing of floor joists can support the victim's weight and at the same time allow for more evenly distributed heat circulation around the body as it remains suspended. Similar to the metal coil bed springs, the larger, more recognizable portions of the body often remain suspended on the structural floor joists while the smaller detached burned bone segments can fall into the fire debris of the lower level or onto the ground surface (manufactured home / crawl space).

2.10 Collapse into a Lower Level

If the floor has been thermally compromised, the charred floor joists may fail under the weight of the body and / or furnishings. Collapse of the floor and exposure into a lower level can introduce a new environment where the body may continue render and burn in the fire debris (Figure 2.7). If the body falls through the burnt floor joists, there's a potential for it getting caught in wiring, duct work, or other construction materials during the descent. Exposed and burnt bones can fracture from impact with any of these materials or from falling into the next layer itself can cause additional fragmentation of fragile burned bones and teeth. Larger fallen debris (charred joists, refrigerator, ductwork, roof tiles) can also crash down on top of fragile, burnt tissues of the body, which has the potential to increase burned bone fragmentation and distribution within the fire scene.

After descending into the next level, the new environment may also contain a burning / smoldering fire debris layer. This layer and any additional fallen fire

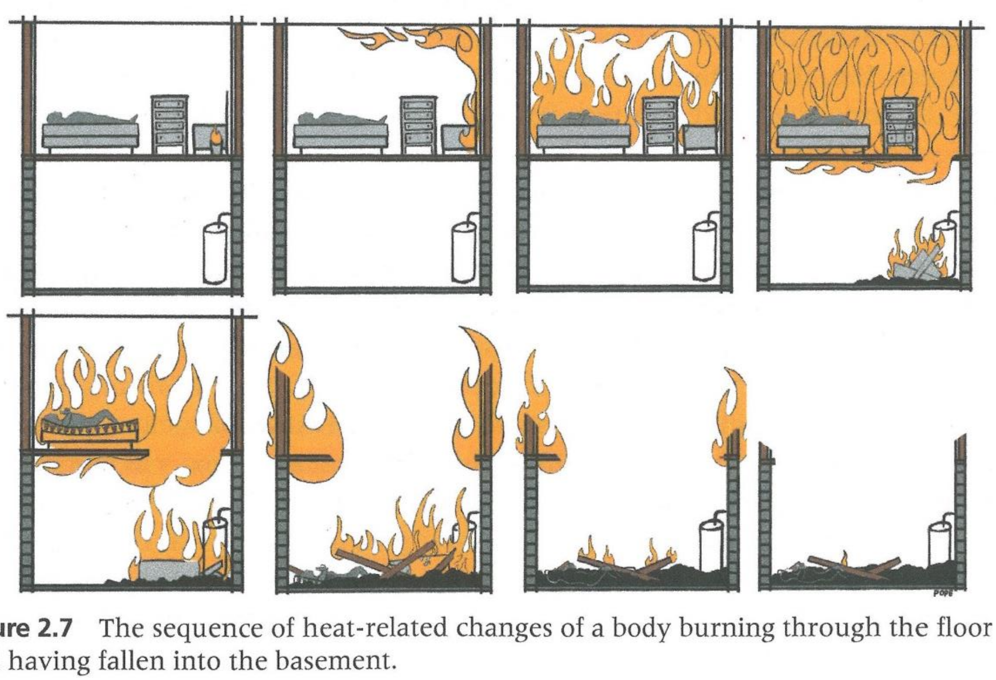

Figure 2.7 The sequence of heat-related changes of a body burning through the floor and having fallen into the basement.

debris (charred wood and drywall / gypsum board / construction materials) around and on top of the body can result in protection of these soft and skeletonized tissues of the body from direct flame impingement, thus results in preservation of the buried surfaces. In cases of partial burial within the fire debris, the exposed surfaces of the body above the debris line (face, arms, knees) can continue to burn, in contrast with the preserved and desiccated tissues that remain buried in smoldering fire debris and protected from open flames. Search and recovery may be more complex in these cases as layers of fire debris around and under the body should be searched and dry screened for identifying any fragmentary burned human remains (burned bones and teeth) along with any detached segments of the body (hands, feet, arms, legs, and cranial fragments). The distribution of skeletal fragments may be more complex, with smaller pieces scattered within the stratified layers of fire debris. In these cases, advanced archaeological techniques of careful hand excavation, and dry screening the fire debris around and under the body are necessary to ensure maximum recovery of the victim's remains.

2.11 Vehicle Fires

Compared to a structure fire, a vehicle fire occurs in a small, metal container. Vehicles have limited interior space and large amounts of synthetic combustible materials (plastics, fabrics, foam, and insulation) within the passenger compartment (Icove *et al.*, 2009; DeHaan and Icove, 2012). Vehicles can have elevated bucket seats for the front driver and passenger, and in some cases a broad metal bench for the backseat (some sedans / trucks), or bucket-style rear seating, which are more common in SUVs and minivans. Most of the vehicle's exterior and interior metal framework survives the fire, unlike most of the previously discussed wooden furnishings in structure fires that can experience thermal degradation and total loss. In a vehicle fire, these materials can produce unique burn patterns, depending on where the body is located: front passenger seat, back passenger seat, or inside the trunk.

The vehicle's smaller contained environment can quickly swell with flames if there is adequate ventilation during the fire's growth and development (from a cracked / opened window or door). Within minutes (or seconds, from an impact / collision or from use of ignitable liquids) the interior space can become a fully involved fire with turbulent flames surrounding the exposed surfaces of the victim's body (Icove *et al.*, 2009; DeHaan and Icove, 2012). The fire's size grows and extends through openings in the thermally compromised windshield, windows, or rear window, which provides additional ventilation and heat circulation that sustains the fire's growth and development. Initially, surfaces of the body that remain in direct or close contact with the seating materials, such as the backside of the torso and upper legs can remain better preserved than the exposed surfaces on the front of the body (seated position). As the seat covering materials (fabric, synthetic, leather) and cushioning burns away, these once protected areas become exposed to heat and flames. Areas of the body that remain in direct or close contact with flat surfaces of the doors, seats, floorboards, or other broad surfaces may be shielded from the turbulent flames and may have less burn damage when compared to the fully exposed front surfaces of the body.

As the fire's size diminishes, the smaller flames that are present within the passenger compartment space continue to burn in the front passenger compartment under the burnt dash from melted plastics and under the body from rendered subcutaneous fat accumulating in the floorboard that provides direct and radiant heat sources to the body. For some sedans / trucks, once the backseat cushioning materials have been thermally compromised, it exposes the internal metal framework dividing the rear passenger compartment and trunk with flames that can surround the upper body. A vehicle fire is a contained scene where any separated bone fragments fall into accumulated fire debris on the floorboard or base of the trunk.

2.12 Driver and Passenger Space

The body that is seated in the front driver or passenger bucket-style seats remains elevated above the floorboard surface during the fire. Common fuels in the passenger compartment of the vehicle can include carpet, upholstery (fabric, synthetic, leather), foam, plastics, rubber, and insulation materials. Within seconds or minutes, flames can engulf the interior that can produce direct and radiant heat damage on the front surfaces of the head, chest, abdomen, arms, and legs, while the backsides of the upper legs and torso remain temporarily protected by direct contact with the seat cushions. The arms can freely flex and move around the chest, while the bulkier upper legs spread apart from the flexed knees from the original seated position.

After the upholstery and foam cushions have been consumed, the remaining underlying wire framework of the bucket-style seat elevates and supports the body's weight throughout the duration of the fire. The back and base of the bucket-style seat consists of a metal frame work with wire springs that provides openings for circulation of heat around more surfaces of the body (Figure 2.8). This configuration is similar to the metal coil spring framework of a mattress and boxsprings, where the body remains elevated above the floor surface during the fire and receives more evenly distributed burn patterns on the exposed surfaces, particularly involving the upper body. Elevation by the metal framework of the bucket-style seat frame allows for the body's rendered subcutaneous fat to drip below into the fire debris layer directly under the body, both fueling the fire in the floorboard and burning as smaller flames on the body's carbonized tissues. This process can last for hours if the fire was not extinguished at an earlier point. The larger recognizable portion of the body often remains elevated in the seated position while smaller burned bone fragments may be present in fire debris in the floorboard in front of, under, and behind the seated victim.

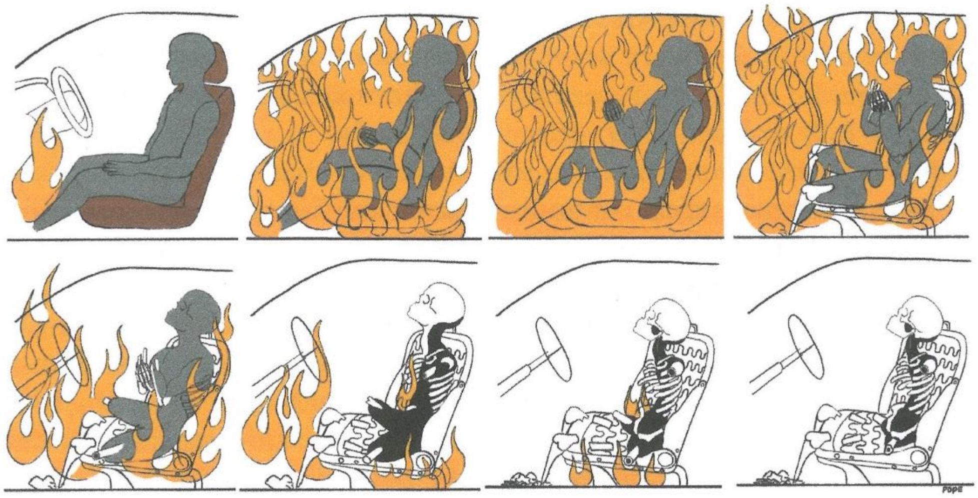

Figure 2.8 The sequence of heat-related changes of a body burning in the front passenger compartment.

2.13 Rear Passenger Space with Bench Seats

The rear passenger space receives the same amount of heat exposure in a vehicle fire when fully involved. Rear passenger seating construction can include an enlongated bench seat or elevated bucket-style seats. The bucket-style rear seats are similar in construction as the front passenger seats that keep the body elevated within the passenger compartment during the fire. For some vehicles, the rear seat may consist of a broad flat metal bench (under the cushions), which may be found in some sedans and trucks. Behind the cushioning, the upper back portion of the rear passenger seat is constructed of a metal framework of springs or perforated metal backing, which allows for direct flame impingement later during the fire that extends to the body from the trunk area once it is compromised by the flames. Burn patterns and soft tissue preservation for rear-seat victims may differ slightly from burn patterns and extent of thermal damage observed in the front passenger seats, sometimes with slightly better preservation of the lower body from remaining in direct contact with the metal bench seat. In this situation, the body does not remain elevated above the metal framework and there are no areas directly below the body for collecting rendered fat to burn as open flames except in the floorboard.

2.14 Trunk Environment

The trunk environment with a body inside is a smaller contained space when compared to the passenger compartment, with its enclosed and confined space (Figure 2.9). The trunk space is primarily a metal box that retains heat and flames

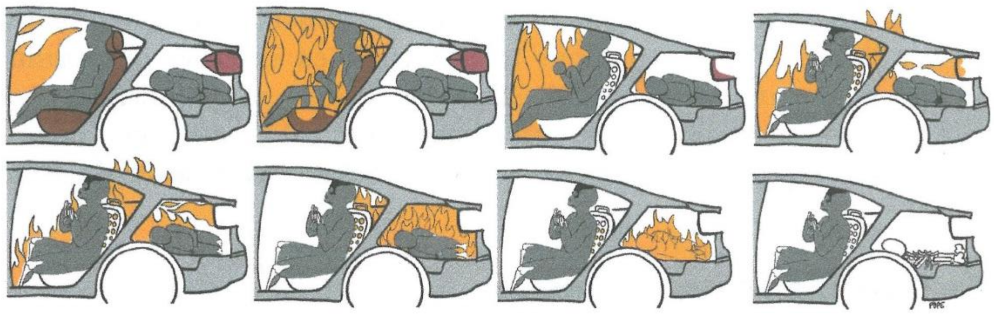

Figure 2.9 The sequence of heat-related changes of a body burning in the back seat and trunk.

after proper ventilation is available through the compromised upper back seat framework and melted taillight openings. In some cases, The body within may be partially flexed to fit the tight space. Before the flames penetrate through the trunk space, the interior remains protected from the main passenger compartment fire (unless it was the origin of the fire). Once the rear seat materials have become thermally compromised, heat and flames travel into the trunk space and surround the exposed surfaces of the body. Controlled ventilation through the openings of the tail lights results in concentrated flames passing over the body and into the interior back seat passenger compartment space. In cases of prolonged burning (hours), the overall mass of the body becomes reduced as charred and carbonized soft tissues and burned bones and fragmention. The presence or absence of a spare tire inside the trunk factors into whether the body remains in direct contact with the trunk base or partially elevated on the metal rim. The rubber tire is a fuel source that burns under and around the body. After the materials have been consumed, it can result in more evenly distributed heat circulation and exposure to flames around exposed surfaces of the victim's body. In contrast, a body that is lying in direct contact with the flat trunk base remains protected longer from lack of flame impingement while the exposed layered tissues continue to burn (longer preservation vs. quicker consumption). A body that remains partially elevated on the metal tire rim allows the rendered subcutaneous fat to drip and burn under the body in the fire debris within the wheel well.

Typically, a trunk fire burns later than the passenger compartment because the space needs proper ventilation and flames. After the upper backseat cushioning materials burn have through coupled with the presence of openings from the melted taillights, then cross ventilation occurs and combustible fuels in the trunk can ignite and become engulfed in flames around the body (similar to the conditions inside a commercial crematorium with an ideal forced gas / air mixture). Exposed surfaces of the body inside this confined space becomes a target object as the flames that travel through the smaller openings in the metal framework of the trunk, over the exposed surfaces of the body, and into the car's interior through the burned metal framework of the back seat, which can turn the trunk into a miniature crematorium with the proper combinations of heat, fuels, and controlled ventilation. These conditions in this confined space environment can render a body to partial or completely skeletonized charred and calcined bones if allowed to burn for several hours. Any charred and calcined skeletal fragments will remain preserved in the fire debris inside the base or wheel well of the trunk.

2.15 Confined Space Fires

Bodies that are burned inside tight spaces such as burn barrels, wood stoves / fireplaces, or trunks are subjected to a unique fire environment. Burning a body within these confined spaces requires adequate time, fuels, and often human activity to maintain the fire. Combustible fuels may already be present inside the space (trunk or burn barrel) or would need to be imported into the confined space (wood, ignitable liquids) in addition to the body inside. Burn barrels and wood stoves are smaller spaces; when a human body fills them, it doesn't burn very well initially (Figure 2.10). Inside a burn barrel or wood stove, the body occupies most of the space, with large surfaces of skin remaining in direct contact with the floor / base and walls. Also, burn barrels and wood stoves need a steady supply of fuel to begin rendering the body's fat – a slow process that requires the frequent addition of wood or fuels to maintain the fire. Inside, small flames burn in vacancies that are not occupied by the body's mass. Moderate attendance may be necessary at the site, to fuel and refuel each time the flames diminsh in size. As the fire debris layer grows deeper, it becomes a wicking material for the body's rendered subcutaneous fat to burn as small flames around the base.

Fuels may still be added repeatedly for hours afterward. However, the deliberate activities by the perpetrator of intentionally stoking and crushing the fragile burned bones and charred tissues can expedite the burning process since the smaller segments burn more efficiently and more space becomes available for the addition of more fuels around the body during the burning process. Gradually, the body's mass reduces in size, at which point the fire can be left to smolder for hours or days. The burn barrel / wood stove is a small, contained scene that retains the burnt skeletal fragments and teeth inside unless if there were

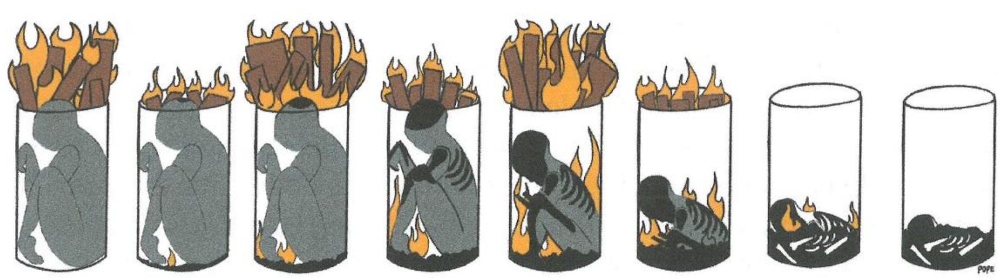

Figure 2.10 The sequence of heat-related changes of a body burning within a confined space environment.

openings in the side / bottom, or if the remains were transported to a different location.

2.16 Outdoor Space Fires

Fires that occur in outdoor environments, where the airflow is unlimited, can burn differently from the previously described enclosed environments of structures, vehicles, and confined spaces. The fire's size and duration depends on the types / amounts of fuels used, human involvement (in some cases), landscape environment (open / secluded), and weather conditions (dry, wind, rain). Naturally occurring wildfires or fires caused by lightening are also examples of outdoor fatal fire scenes.

Outdoor fatal fire scenes can also result when a perpetrator intentionally burns the victim's body to destroy evidence of a crime and / or personal identity. Individual outdoor incendiary fatal fire scenes can vary according to the size and types of combustible materials that were used as fuels for the debris pile – household furnishings, branches / logs, rubber tires, wood pallets, or the use of ignitable liquids alone. The landscape and surrounding environment are other variables that can influence the amount of burn damage – for example whether the fire occurs in a wide, open space (visible on the landscape) or in a secluded wooded / protected area with a fire that may go undetected, both of which can be affected by changes in winds and weather conditions. Previous or current wet conditions (precipitation) may hamper the fire's development and duration, whereas dry conditions and vegetation are more ideal combustible materials for burning.

2.17 Ignitable Liquids on Bodies

Bodies that are burned after being doused with ignitable liquids undergo a rapid set of heat-related changes before the liquid accelerants evaporate and burn away from the skin surfaces several minutes later. Ignitable liquids that are poured onto the body (and clothing) can produce a flammable vapor fire after ignition that can surround the body and, in some cases, can also burn surrounding vegetation, clothing, and / or proximate objects (tree / structure) depending on the size of the fire. The wicking properties of clothing retains ignitable liquids longer than naked skin alone. Ignitable liquids coats the skin and flows downward off the curved surfaces and pools at the body / ground junction around the victim's body. Clothing absorbed and retained the ignitable liquids that burned in the fabrics above the skin surface and temporarily provided protection from direct flame impingement. Superficial heat-related changes to the skin occur rapidly after ignition and can include scorched / singed skin, discoloration, blisters, skin splits, possible exposed and rendered subcutaneous fat, and early flexion of the extremities, beginning with the flexed finger joints. Minutes later, the flames diminish to several inches above the ground, burning primarily in charred clothing remnants around areas of the torso, thighs, shoulders, and neck at the body-ground junction. These smaller flames can self-extinguish or continue to burn if rendered subcutaneous fat is exposed and absorbed into charred clothing, dry vegetation, and fire debris which are wicking materials that sustain the burning process (DeHaan *et al.*, 1999; DeHaan and Nurbakhsh, 2001). After several minutes, the ignitable liquids on bare skin had expended (except in clothing / permeable materials protected under the body) and no longer contributed to the fire's development. Often with incendiary outdoor fires, ignitable liquids can be used to start the fire but have little effect on the body after several minutes of burning unless clothing or other wicking absorptive materials are present under and around the body to sustain the open flames.

2.18 Burning Outdoor Debris Piles

The arrangement of larger combustible fuels and the body's location within these materials is another important variable in an outdoor setting. The body can be buried lying on the ground underneath the debris pile (Figure 2.11) or positioned higher for more of a funeral pyre or bonfire configuration, where the body rests on top of or within the debris pile (Figure 2.12). Suspension on or within the debris pile (wood pallets, logs) during the fire allows for more evenly distributed heat exposure and thermal damage to the body's surfaces from heat circulation, which can be similar to the scenarios described earlier with the body partially elevated on the burned mattress springs and wireframe bucket-style seats in a vehicle.

If the body remains suspended within the burn pile during the fire, the rendered subcutaneous fat can wick into the charred wooden fire debris and burn under the body as well as on carbonized tissues. After the combustible fuels that were once supporting the body have burned away, the layered soft tissues of the body may continue to burn on the ground in the fire debris layer with smaller flames for hours from burning rendered subcutaneous fat. Additionally, any

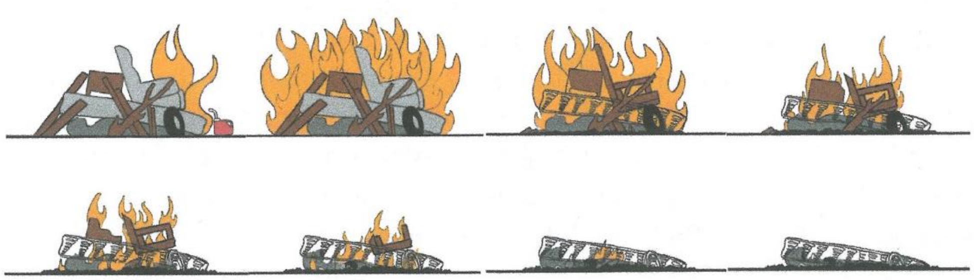

Figure 2.11 The sequence of heat-related changes of a body burning in an outdoor space buried under the fire debris.

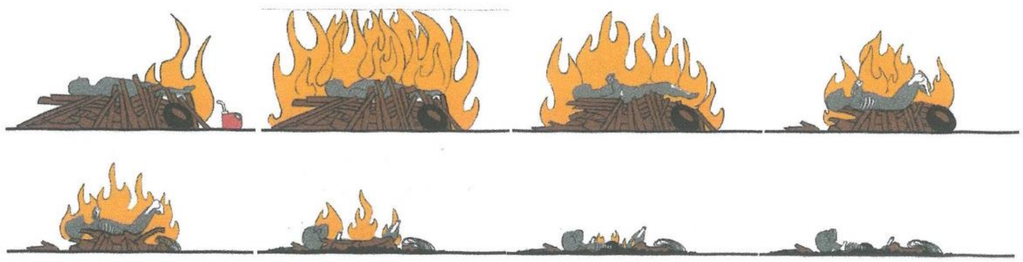

Figure 2.12 The sequence of heat-related changes of a body burning in an outdoor space on top of the fire debris pile.

human activity of tending to the fire by adding fuels and maintaining the fire can factor into the duration and extent of thermal damage to the burned body. Stoking the fire debris can cause additional fragmentation of burnt bones, leaving them present with in the fire debris around, on top of, and under the body. In contrast, a body that is buried under a large debris pile remains in direct contact with the ground which results in protected surfaces during the fire. In some cases, the extremities of the body may be restricted from movement into the pugilistic posture. For example if a mattress or large pieces of furnishings are on top of the body, these can pin or restrict the natural heat-related movements of the extremities, especially for flexion of the arms during the fire. On the other hand, a body that is located higher within the debris pile may lack such confining restrictions from attaining the pugilistic posture in the absence of heavy objects on top of the limbs. The main difference between the two locations within the burning debris pile is that a buried body may be restricted from fully developing the pugilistic posture and which may result in better protection and preservation of the victim's burned body when compared to the fire conditions involving the partially suspended body in the pyre or bonfire, that incurred earlier heat exposure to more surfaces of the body before falling into the protective layers of fire debris.

2.19 Post-Fire Fragmentation of Burnt Bones

This section introduces variables and pitfalls that can relate to activities of the search and recovery of burned human remains from residential structure fires, vehicle fires, outdoor spaces, and sometimes confined space fatal fire scenes. The activities associated with firefighting can potentially alter the body's original burnt condition. Several conditions can cause additional fragmentation of exposed and burnt bones that include normal exposure to heat as protective muscles burn away; movement and flexion of the limbs; crushing from any collapsed debris; damage from suppression; search and recovery methods; incomplete recovery, handling; and transport from the fatal fire scene to the Medical Examiner / Coroner's Office for forensic examination of the burned body.

2.20 Suppression

Fractures to burned bone can occur both during and in some cases after the fire. Extinguishing any burning fire scene is a necessary action to protect life and property. Common firefighting tactics involve using hoses with pressurized water as a method of extinguishment. A fire-hose nozzle can produce a straight stream (directly focused column of highly pressurized water), fogging (shower effect) or a graduated combination (Figure 2.13). There are notable differences between the two methods when considering physical evidence preservation of burnt human remains; however, it is not always known during firefighting efforts whether victims are inside the residence / vehicle. The straight stream method focuses a column of highly pressurized water that can cause extensive damage to the body if directly hit with force, which can cause fracturing, fragmentation, and dispersal of fragile burnt bone fragments on and around the body within the fire scene. Soft tissues and organs may also be affected when directly struck with the pressurized water stream and can result in damaged or projected internal organs outside of the abdominal cavity, and can result in disfigured charred muscles and soft tissues.

During suppression, portions of the fragile burnt bones can break away, not because of the temperature differential of cold water on a hot body, but instead from the direct force and impact of the pressurized water stream striking the surfaces of the victim's body. This suppression related damage is most commonly observed for the head, where the top of the cranial vault appears to be partially missing with the brain exposed and those smaller fragments be found distributed around the body within the fatal fire scene. The skull does not shatter or "explode" from internal heating or expansion of the brain by the fire, but instead the cranial bone fragments from being forcefully and directly struck with a pressurized water column. Also if furnishings under or surrounding the body are directly struck with the forceful water column from the straight stream method of extinguishment, this can cause shifting, collapse, and / or the deposit of additional fire debris (walls / ceiling) onto the victim's body. In contrast, the method of fogging or showering using the same pressurized water and results in better preservation

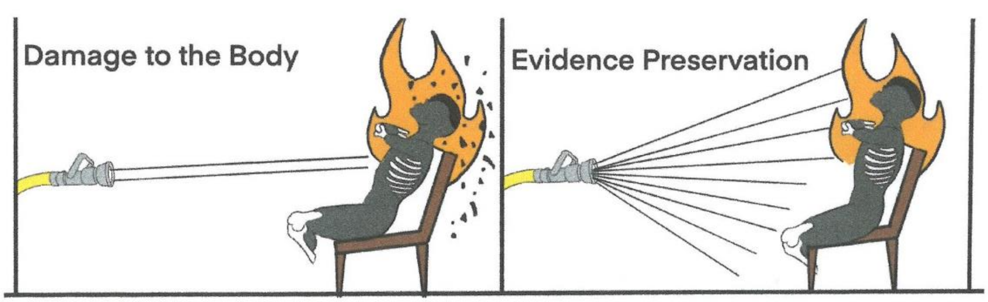

Figure 2.13 The sequence of heat-related changes of a body burning in an outdoor space buried under the fire debris. Suppression damage to the body from pressurized water from a fire hose: Straight stream directly impacts the tissues and burned bones, while fogging preserves evidence of burned human remains.

of the victim's burned remains as it essentially "rains" around the body, causing less post-fire damage to the burned soft and skeletonized tissues of the body.

2.21 Recovery and Transport from Fatal Fire Scenes

After the fire has been extinguished, the activities that are associated with overhaul and search through the fire scene has the potential to create additional crushing damage caused by heavy boots and dragging hoses. If the body is located this way, the post-fire damage to the burned body should be photographically documented and noted. Once a body is discovered, the process of scene documentation begins, using forensic methods of crime scene photography, archaeological gridding / mapping, careful hand excavation of fire debris, and dry screening of fire debris within the vicinity of the victim's body to ensure complete recovery. Certain types of fire debris can look similar to burnt human bones. For example the warped and curved pieces of drywall / gypsum board can look similar to the curved cranial bone fragments. Pieces of melted plastics can have a smooth outer surface that is similar to smooth cortical bone, with inner air bubbles that appear similar to trabecular bone. Door insulation from vehicles curls and may be confused with fragmentary calcined ribs.

Recovery entails removal of the body from its original in-situ context within the fire scene, which can produce additional damage to fragile burnt bones if handled improperly. In some cases, the largest and most recognizable portion of the body (charred armless, legless torso) is often removed, while leaving behind smaller burned bone fragments that can be subjected to crushing from investigators walking through the fire scene, or later discovered by family members returning later to salvage any personal belongings from their burned property. The level of experience and training of the body removal personnel can factor in the completeness of the recovery process. It is important to consider whether they have been trained in the forensic recovery techniques of fatal fire victims or if it was conducted by untrained personnel from a contracted body removal transport services. Another type of improper handling is when the fragile burnt bodies are moved by grabbing the wrists and ankles to drag or carry the victim outside of the fire scene, since there is a possibility of producing additional post-fire fractures to these burned and sometimes the unburned long bones of the distal extremities. If this does occur it is relatively easy to distinguish the post-fire break from improper handling versus perimortem traumatic injury, by examining the cross section at the fractured margins that are crisp, rich and brightly colored throughout. The post-fire cross sections of a fractured charred long bone can appear as a superficially blackened layer of the cortical surface, while underlying inner structures remain as fresh unburned yellow bone. Cross sections of calcined long bones can have a superficial gray/white layer of cortical bone with the underlying inner structures that remain charred black. Cross sections from the prolonged calcination of long bones transitions into a more uniform white/gray color throughout and can include heat-related fractures (surface and complete fractures) with possible shrinkage and warping. These layered heat-related color changes can also apply to post-fire fractures of cranial bone, the mandible, ribs, and other exposed burned bone surfaces. Another common mistake is when the body bag may be placed directly next to the fire victim before searching, removing, and sifting for burned bone fragments in the surrounding fire debris. Crushing can occur from boots of investigators or body transport service personnel while moving the body into the body bag, or additional fragmentation can result from pulverizing smaller burned bones under the weight of the victim's body during movement and placement into the body bag. If possible, any additional smaller burned bone fragments should be collected and transported within a rigid cardboard box or in other protective materials (loosely formed aluminum foil, evidence bags) and submitted along with the victim's body to the ME / Coroner's office for forensic examination. A majority of the time these smaller burned bone pieces are collected and then tossed directly into the body bag with the bulky victim's body inside and and then transported which can result in additional pulverization of those smaller bones.

Once the decedent is documented and sealed inside the body bag, carrying it through the scene can be problematic if the body bag sags or hits objects on its way out. Movement of a rigid and fragile burnt body within a flexible body bag may produce additional crushing damage to the exposed burnt bones. However, the use of a rigid backboard under the body supports and more evenly distributes the body's weight which can minimize the problem of excessive fragmentation of burned bones within the body bag. Also the use of the more durable disaster pouch body bags, which are constructed of a more rigid and heavier material, can produce unnecessary pressure points against the fragile burned structures of the cranial and facial bones, rib surfaces, forearms and wrist, and the flexed knees and lower legs during handling and transport. An alternative to this problem would be the use of a rigid and protective cremation box from a funeral home to safely transport the victim's fragile burned body. Strapping the victim's burned body onto the body removal gurney may cause localized crushing of the flexed arms, ribs, and flexed legs as the straps are tightly cinched down across the body to secure the remains for transport to the Medical Examiner / Coroner's Office. Before the forensic pathologist (or anthropologist) examines the victim's burned body, other types of handling and manipulations can occur during the process of receiving / transfer of victim's fragile burned body onto a morgue gurney followed by movement and rotation of the body for multiple radiographs, then the postmortem examination (rotating face up and face down), followed by the destructive autopsy procedures, all of which can occur before the forensic anthropologist conducts their examination of the burned bones. Understanding how and when these different heat-related and post-fire fractures occur can improve the analysis of burnt human remains regarding differentiating significant burn patterns from post-fire alterations that may be encountered in forensic anthropology casework involving burned human remains.

2.22 Conclusions

While the heat-related damage to bodies in fires can share similarities of the overall burn patterns, these are also influenced by variables (i.e. fuel loads, duration, interior dimensions, ventilation, furnishings, etc.) in the environment in which the body burned. The body's position during the fire – as lying face up or face down, remaining elevated during the fire or remaining in direct contact with surfaces of the the floor / ground / furnishings influences the areas of surface exposure and protection / preservation, overall burn patterns, and in some cases, the distribution of burned bone fragments located around the body within the fire debris at the fatal fire scene. Fragmentary remains of burnt bones and teeth can be recovered depending on the final condition of the body and scene within the surrounding fire debris. Recovery of these smaller burned skeletal fragments and in some cases, dentition along with the main body provides a more comprehensive picture of how the body burned. Finally, an awareness of the many post-mortem transformations that layered tissues of the body undergoes both during the fire (heat-related changes) and after (search, recovery, transport) can improve the forensic analysis of burnt human remains by the forensic anthropologist, especially for differentiating heat-related and post-fire fractures from any perimortem traumatic injury.

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