CHAPTER 10

How Human Bodies Burn

The Process of Thermal Damage, Body Movement, and Shifting Fuel Loads

Alison Galloway, Chelsey Juarez, and Elayne Pope

In planning and training to recover bodies following a fatal wildfire, knowing what to expect is critical. Search and rescue teams must prepare for a very wide range of events, including mountain rescue, water rescue/recovery, missing individuals with diminished capacity, and collection of evidence. Few have specific training in the recovery of burned remains and especially not those in which the damage to the remains is as extensive as frequently seen in wildfires. Common problems encountered in the search and recovery efforts are (1) the expectation of finding a "full body" so that searches either miss or trample over the fragile remains produced by the fire or (2) the expectation that anybody has been reduced to ash so that any small item that looks vaguely bonelike is assumed to be all that is left of the person. The latter situation results in many "false positives" during the search efforts, each of which must be cleared.

In addition to understanding *how* a body looks after a wildfire, we must also understand that *where* a body will be found will affect how it burns. It is important to understand how bodies are changed by fire, particularly one that results in complete or almost complete cremation of the remains (Bohnert et al., 1998; Pope, 2007; Symes et al., 2014).

There are usually three situations in which bodies are found: (1) outdoors, when the victim was trying to flee on foot, often between the residence and a vehicle or after having left a vehicle blocked on the road, (2) when the victim was still inside a vehicle overtaken by the fire, and (3) where the victim was inside a structure. The condition of the body typically varies by the location, although those in vehicles and structures may be similar in the level of destruction.

10.1 INITIAL CONDITIONS

In wildfires, the victim usually does not die during a slow-burning fire that produces high levels of carbon monoxide, resulting in unconsciousness due to carbon monoxide poisoning. Victims die relatively quickly once the fire descends but may have taken actions in anticipation of the fire, such as fleeing, sheltering, or showing acceptance of the inevitable (see Chapter 9). They may die from the inhalation of hyper-heated air, burning the air passages, or from the massive superficial burning.

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Once dead, the body collapses (Figure 10.1). The fire will begin by burning the hair and clothing. Skin surfaces that are exposed to heat will begin to discolor to tan, reddish brown, or brown and then scorch, shrink, and develop blisters (Moritz, 1949; Adelson, 1954). Original skin pigmentation must be taken into consideration when assessing the color changes as darkly pigmented skin will appear dark, tightened, and shrunken without first appearing tan or light brown. The blisters typically form in and around the areas of skin change so that there is a gradation from unburned skin to blistered skin to discolored skin. Blisters are not a sign of vitality unless they are accompanied by inflammation.

Areas of skin that are in direct contact with surfaces remain protected between the body and the ground/floor substrate. These areas will be unburned despite extensive damage in the areas where heat exposure is greater. Similarly, areas that have tight clothing also tend to be somewhat protected, depending on the flammability of the material and position of the body as face up, face down, or lying on their side.

With superficial burning, body movement is minimal. There may be some deformation of facial features that include shrinking of the nose and ears along with retraction of the lips and protrusion of the tongue. Tongue protrusion is a natural heat-related occurrence and does not signify that the person was alive at the time of burning (Bohnert & Hejna, 2016; Madea & Doberentz, 2015 [contra Bernitz et al., 2014]). Some splaying of the fingers and toes (if barefoot) may be apparent but the contraction of the larger muscles to produce larger movement will require more heat. One must also be aware that bodies may be positioned in such a way that thermal damage will be differential even in these early stages. For example, if the body is seated, upper areas may be more heavily damaged. If the person was on an item of furniture such as a bed or chair, that item will begin burning at the same time that the body is affected. Those areas closest to any available combustible fuel source will exhibit more severe burn damage. Body segments that are closest to burning materials can move or lean toward the heat source.

If the fuel load around the body is limited, as is often the case when the body is found in an open space, the damage often terminates at this stage. The body would be

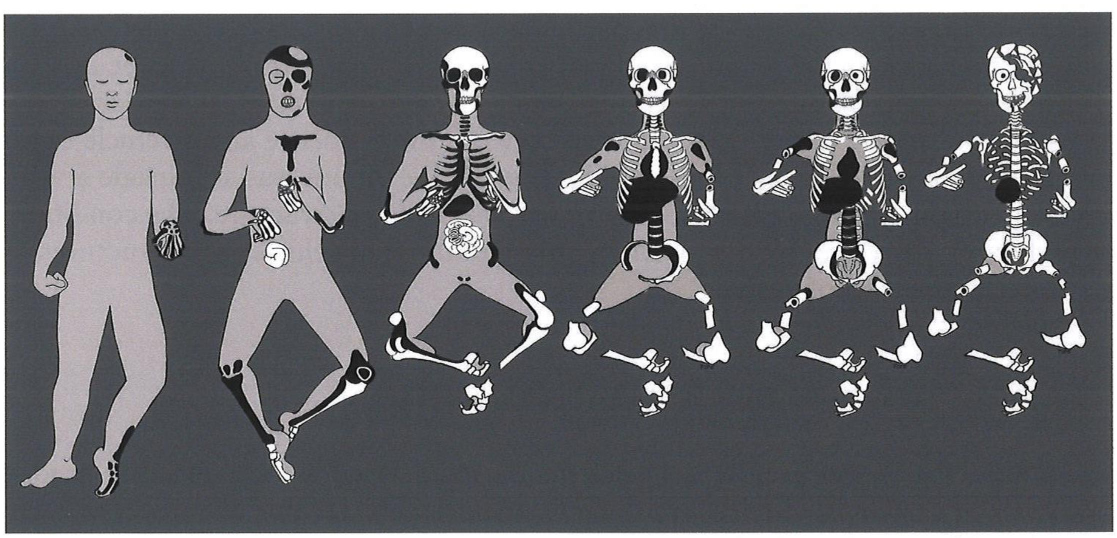

FIGURE 10.1 Frontal view of bodies through the burning stages showing loss of soft tissue and charring, calcination, and fragmentation of skeletal elements.

found intact although much of the clothing may be gone. Synthetic fabrics tend to burn or melt quickly with heat. Natural fabrics, such as cotton and silk, burn quickly but without melting and may self-extinguish, particularly if pressed between the body and another surface. However, the discolored, blistered body with remnants of clothing is the usual result.

10.2 DAMAGE BY SURROUNDING FUEL LOAD

In non-wildfire situations, it is common that fire suppression will arrive relatively early in the burning sequence. Bodies are found intact, as scorched or charred remains. However, in wildfires, fire suppression is usually nonexistent and the burning of a vehicle or structure will continue unchecked. Damage to the body will also continue.

10.2.1 Superficial Changes and Body Movement

If there is still external fuel available, such as furniture, structural elements, or interior of a vehicle, then the damage to the body will also increase as these fuel sources are consumed by the flames. The surface of the skin changes from discoloration to charred. Blistering continues along the margins and the shrinkage of skin will cause splits to occur. These skin splits expose the underlying layers, including subcutaneous fat followed by skeletal muscles.

At this point, there will be noticeable movement of the hands, feet, wrists, and ankles. The fingers will splay apart, and the small flexor muscles begin to contract, causing the fingers to curl inward along with a flexed wrist. This is a normal reaction to the fire and does not indicate any voluntary or pre-fire activity on the part of the deceased. The toes also splay followed by flexion. The arched foot and ankles extend downward as the shrunken Achilles tendon and calf muscles shorten.

Charred skin surfaces and skin splits expand to expose more and more of the underlying tissues, including subcutaneous fat and skeletal muscles. Some of these fats will be liquified by the heat, producing an oily sheen to the surface. These exposed areas are initially not charred, contrasting with the charred skin surrounding the split. However, as the areas of skin are consumed and the underlying tissue also charred, the entire exposed body will be seen simply as a blackened surface. Only closer inspection will show that there is skeletal muscle, fat, and in some cases, bone exposed.

10.2.2 Soft Tissue Loss and Bone Damage

The head will show retraction of the lips, exposing the anterior dentition. The posterior dentition tends to endure longer due to protection by the cheek musculature (Delattre, 2000) but will eventually also succumb to the fire. The heat will cause the highly mineralized dental enamel to fracture (Campbell et al., 2011; Federchook et al., 2018). Enamel and the underlying dentine have differing levels of organic material and therefore shrink at different rates. The enamel, which has low moisture and low organic material, tends to stay the same size but the higher organic content of the dentine causes it to shrink. The dentine then pulls inward as it shrinks and portions of the enamel will eventually sluff away. The dentine crown will shatter if hit with water during fire suppression or by falling debris; otherwise, it will passively fracture and fragment with only the roots found intact remaining within the jaw (molars) or as fragments in the substrate.

The facial features will also continue to deform so that the nose, lips, eyebrows, and ears gradually shrink and burn. The tongue forms a protective plug in the oral cavity as it often protrudes from the mouth due to swelling from heat changes. Eyelids may temporarily shrink, making the eyes appear open but then burn away to leave a charred tissue mass in the orbits.

Areas of the body where the skin is relatively thin and close to the bone, such as on the scalp of the forehead, the shins, and the flexed knuckles are vulnerable to heat damage. The skin will be consumed quickly, exposing the underlying bone. Exposed bone initially appears as fresh and once exposed to heat, it will appear discolored (yellow/white [greasy], then brown [greasy], and then brown/black), then charred. In the final stage of calcination, the bone will appear gray, as the organic materials have burned away leaving only a brittle inorganic bone structure that retains all the features as an unburned skeleton.

Body movement during this burning process accelerates significantly. The neck muscles contract so that the head is tilted backward, and the chin extended anteriorly. The arms begin to reposition into the pugilistic posture with the elbows and wrists flexed with clenched hands and fingers. In the pugilistic stance, the flexed and internally rotated arms and flexed hand, and wrists are to the sides and front of the chest along with partially bent knees, which appear as if the person was fighting (boxer pose), hence the name. As the wrist and forearm area burns, the hand will detach either by heat fractures through distal radius and ulna or as the tendons and ligament are burned through at the wrist. The remaining hand is repositioned proximally with the shrinking forearm muscles, where it will be held by the remaining tendons of the skeletal muscles. The elbows and upper arm will move above the substrate when the body is supine with arms flexed beside and/or over the chest. In some cases, the arms may appear over the head, which results from a combination of proximity to heat sources during the later stages of the fire and contracture of deeper remaining muscles of the shoulder and back, both of which influence the arm's final position.

The legs will also move. As the heat is applied to the larger muscles of the calves and thighs, larger body movement is seen, though delayed in comparison to the movements of the smaller arm muscles of the same body. The Achilles tendon shrinks and calf muscles contract pulling the ankle and foot downward into full extension, so the toes appear pointed. The front of the shin (anterior tibia) is charred bone and fractures above the ankle, causing the foot to detach from the lower leg. The remnants of the foot may either fall to the substrate or remain attached and drawn into the larger calf muscles on the back of the leg. The knees flex, causing the upper legs to spread apart due to the weight of the still-fleshed thighs. The heels or lower parts of the leg are drawn together along the midline, forming a "ballerina" pose. At this time, the adductor muscles at the hip and also pull the thighs wide apart, resulting in a splaying of the thighs that could be incorrectly interpreted as a sexual assault. This positioning of the legs is also attributable to the bulky thigh musculature where its thicker muscle layers take longer to induce the flexion at the hip and knee. Movement of the knee continues until it is in full flexion by which time the distal end of the femur is exposed and burned bone at the knee. The bones around the knee will show heat fractures.

On the torso, the fire will continue to burn through the subcutaneous fat layers and skeletal muscles. If the body is in the supine position (face upward), then portions of the internal organs will typically be exposed in the abdominal area outside of the body and appear to be extruding. Rib surfaces are often exposed along the sides of the body and begin the transition from discoloration to charring to calcination. Charred intercostal muscles of the chest wall leave windows between ribs that show the internal aspects of the chest where the heart and lungs will char into hardened black masses, leaving a partial void inside the ribcage.

10.2.3 Deep Tissue and Bone Loss

As the burning continues, the hands and feet will often appear to be lost "from" the body as these areas have very little flesh to protect the bone and have greater surface area for heat exposure. However, the small bones of these areas are one of the most common intact skeletal elements when the recovery is careful. The foot bones will typically be deposited under the ankle area, possibly close to the torso. Portions of the hand and wrist bones may have fallen into the chest area, or around the body depending on the movement and final position of the arms.

As the hands and feet are detached, other joints also are exposed and exhibit fragmentation. This process is most visible in the areas above the ankle, the knee, the wrist, the elbow, and the shoulder. Bone that has been exposed to heat loses its organic component and becomes exceptionally fragile (Thompson, 2005). Bone itself shrinks like skin splits and result in small superficial heat fractures that can appear as linear, longitudinal and transverse, semicircular curved, and jagged checkered (Buikstra & Swegle, 1989; Heglar, 1984; Herrmann & Bennett, 1999; Mayne Correia, 1997; Shipman et al., 1984; Symes et al., 2014; Walker et al., 2008). Additional fractures during the fire may result from falling debris if, for example, in a structural fire there are falling beams, roofing or lighting fixtures. Alternately, the body itself may fall through the floor(s) producing additional postmortem fracturing. However, even absent these factors, heat fracturing alone will cause eventual fragmentation of the skeletal elements. These fragments are, however, relatively large and retain morphological features that may allow for identification.

Heat-induced fractures can be distinguished from pre-fire fractures due to the differential coloration of the fracture margins and the changes in body movement around long bones. Pre-existing complete fractures in long bones allow "scissoring" of the bones as the broken ends slide past one another within the shrinking muscles. Protected areas such as the base of the skull may retain pre-fire fractures even when there is extensive delamination of the upper vault (Bohnert et al., 1997).

Destruction of the face and cranial vault are also seen. Facial anatomy is complex with a melding of very thin bones around the inner orbit and along the nasal opening with thicker bone along the margins of the face. All the thin bones of the face are vulnerable to fragmentation both during and after the fire. Early in the fire, the lower face is protected by the cheek muscles and the subcutaneous fat. However, as these tissues are consumed, the facial bones become calcined and develop heat fractures.

The vault, the dome of the skull, will develop heat fractures to the outer table in the form of delamination and separation of the outer layer (Pope et al., 2004). The bones of the vault consist of two distinct compact layers separated by spongy bone, called the diploe. Because the outer table of bone is most directly subjected to intense heat, this surface shrinks first due to the loss of organic material. When that occurs, the outer portions of the skull fracture through the diploe and may fall off the vault. The inner table is adjacent to the brain, which has high moisture content and is more resistant to heat, so it will fracture secondarily. When the outer table separates, it leaves a textured surface on the skull formed by the diploe, which lies within the hard outer and inner surfaces. Once the vault is breached by a full-thickness heat fracture, the brain itself will char and shrivel, leaving a mass of black carbonized material in the cranial base of the skull.

As the thicker musculature of the cheeks is lost to the flames, the premolars and molars become exposed and fracture similar to the anterior teeth. Roots for these teeth tend to have more structural adherence to the jaw so may be retained in the bone. That adhesion is particularly true for the upper molars, which have three curved roots.

10.2.4 Alterations to the Pattern of Thermal Damage

While this progression is typical of bodies, some factors will alter the pattern. One of the most significant is the effect of constraints on the body that limit movement. In the wildfire situation, this may come about by the collapse of structures onto the body or the presence of nonflammable units (e.g., sides of the car or dashboard) that may limit some limb movements. For this reason, observations about body position should also note surrounding context with copious photography when possible.

A second reason for changes in the pattern of body movement and, consequently, damage to the remains is the loss of substrate. Initially, this substrate is often the item of furniture upon which the person was sitting or lying. Wooden bed frames collapse, leaving only the metal springs of the mattress. This collapse may be uneven, depending on the progression of the fire and the body may be tipped to one side or even rolled onto the floor from the sagging coil springs. Chairs, sofas, and recliners also show similar loss of integrity, essentially spilling the body onto the floor.

However, one of the biggest disruptions in a wildfire, or any non-suppressed fire, is the loss of the floor itself. Most bodies are found in the foundation area of the structure—in manufactured homes, this will be under the I-beams that supported the home. The intact portions and all the fragments of bone are deposited downward with some resulting additional breakage as well as some displacement as this process is also uneven.

10.3 SELF-SUSTAINED BURN DAMAGE

A common misconception is that the damage to the body is equivalent to the fuel load available in the area surrounding the body. This assumption ignores the fact that the body itself provides an active fuel source that can sustain fire long after the surrounding fuels are consumed (DeHaan et al., 1999; DeHaan & Nurbakhsh, 2001; Hejna et al., 2019). Experimental data show that bodies do not elevate deep internal temperature significantly in structural fires for 60 minutes, indicating that this fuel load is not directly responsible for the full destruction of the remains.

The contribution of the victim's body comes from subcutaneous and deep fats and fuels the fire as it is rendered (DeHaan, 2012). The body will begin to burn using the body fats as an additional fuel source from rendered subcutaneous fat that turns to liquefied grease. The rendering process of subcutaneous fat begins early during the fire from exposure through skin splits that release liquefied grease. As the body is penetrated by heat damage, organ fat and marrow also provide additional fuel sources. Rendered fat is absorbed into the surrounding materials (clothing/fabrics, carpet, wood, carbonized tissues) where it has available wicking materials for sustaining the fire. This liquified grease typically pools around the torso and upper thigh areas. However, where the fats accumulate depends on the substrate materials and topography. Some substrates will allow for absorption of fats, while other substrates are less porous and allow for pooling, such as on wood or concrete floor. The transition from fat as a supplemental fuel to the primary fuel begins several minutes into the fire and can last long after the surrounding fire has self-extinguished. Flames several feet to inches high are visible for many hours and the rendering process continues until suppression or natural self-extinguishment.

In a wildfire situation, most fires are not suppressed. Therefore, bodies will continue to burn for hours or even days smoldering in fire debris, long after the fire has passed and the structure or vehicle has been consumed. It is this self-sustained burn that is responsible for the more advanced destruction of the body in the absence of surrounding combustibles.

Eventually, the flames will have consumed most of the soft tissue and transformed the adjacent bone to calcined skeletal remains. Only organs with a considerable density and high moisture content tend to survive this process. The most typical findings are remnants of the heart and liver, both of which can be useful for the extraction of usable DNA (see Chapter 15).

The result that is common in structural and vehicles in wildfires is that the "body" now consists of something along a spectrum beginning with an articulated charred spine from the base of the skull to the pelvis, possibly with proximal (upper) portions of the thigh bone to only calcined bone fragments in some rough approximation of anatomical order. This would be classified as stage 5–6 (Pope et al., n.d.) or stage 5 (Glassman & Crow, 1996). This is the scenario for most of the search and rescue/recovery operations—highly fragmented and heavily damaged bones.

10.4 TYPICAL APPEARANCE OF WILDFIRE BODIES

To return to the points at the beginning of this section, how will bodies appear in the aftermath of a wildfire. For people caught in the open, where there is little surrounding fuel, the burning will be minimal. Hair will typically be singed, and the skin may appear discolored and slightly shrunken. If there is some light fuel around, there may also be blisters. Radiant heat from nearby structures can also cause these changes even if the flames do not directly contact the body. Such remains are usually quickly recognizable and can be retrieved intact.

Victims in vehicles tend to be largely skeletonized but the skulls may be mainly intact. This effect is due to the positioning of the body within the car seats. During the height of the fire, the head is uppermost and within the most intense heat zones, producing significant changes. However, fuel loads within a vehicle are quickly consumed. By the time the vehicle has largely self-extinguished, the head remains well above the area where body fats are pooling and the remaining soft tissue is being consumed.

While there is considerable calcined bone on the skull, it often remains intact in vehicle fires without fire suppression. The rest of the body will also show recognizable skeletal elements. Rendered fats will often pool in the car seat, but some of that pooling may dissipate as the seat itself is consumed. The metal infrastructure of the seat holds the individual above the rendered fat that pools in the floorboard. What may be confusing in wildfire recovery is that there may be multiple victims, and if there was a crash involved, they may have been dislodged from the seat. Because of skull preservation, an estimate of the number of individuals can be made but may need to be adjusted if there are also infants and young children present, where preservation is lessened. However, the presence of human remains in a burned vehicle is usually very obvious. As noted earlier, the base of the skull, spine, and pelvic areas often provide a good means for estimating the minimum number of individuals.

Victims in structures are most heavily damaged because of the effects of the fire, the consequences of the self-sustained burning process, and the damage produced by the collapsing structure. The body may appear as a blackened spine with expansions at the base of the skull, the midsection where the remaining internal organs sit, and at the pelvic area (stage 5–6 in Pope et al., 2022). In the area surrounding the torso, there will be the fragmented remains of other body parts—portions that may be critical for determining the number of individuals present. In multistory structures, more complete cremation is often seen due to the greater fuel load and possible collapse of more than one level of building.

10.5 BODY LOCATION IN STRUCTURES AND PROBLEMATIC SEARCH TECHNIQUES

Problematic search approaches cause further damage to the remains (see Chapter 12). One approach that has been practiced in fire scene search processes is to "shuffle" through the interior of the house or structure until the body is "uncovered." This is not an effective tactic given the extreme level of destruction of the body and the fragility of the remains. However, as the recommended search protocols in this volume advocate, a visual search of the surface is often very effective. The reason that the bodies may be seen from a visual inspection of the debris surface is linked again to the process of burning.

The body is only partially consumed by the surrounding fuel loads in the actual fire of the structure or vehicle. By the time those fuels are consumed and the structural fire has self-extinguished, the remains usually consist of a sizable torso with portions of the limbs and significant soft tissue on the torso, shoulders, and hips. Debris that has fallen on the body often include burned wooden beams and other partially burned material. Throughout the after-fire period, this charcoal and other matter will be reduced to ash only. In the meantime, the body, over which these materials lay, is still burning slowly. The mass of the body tissue forms an elevated surface and the ash falls to the side, leaving the body on the surface. Hence, the body, or what remains of it, is often located on or very close to the surface.

The exception to this situation is when there is non-combustible roofing material. In wildfire areas, metal roofing, whether on a normal structure or a mobile home, will remain although buckled and warped by the heat. Once removed, the remains are often close to the surface of the remaining structure. More difficult is when there is a tile or slate roof that will collapse as the supporting beams are burned through. The result can be a considerable thickness of roofing material over now largely crushed human remains.

It is also important to remember that the effects of burning will be blended with the decomposition process in wildfire situations since many remains will not be collected quickly. While charring seems to inhibit some decomposition, heat damage and the release of bodily fluids will attract insects quickly, accelerating decomposition in some areas of exposed soft tissue (Avila & Goff, 1998; Gruenthal et al., 2012). In some cases, body location can be aided by observation of increased insect activity in the area of burned remains (McIntosh et al., 2017).

10.6 DIFFERENTIATING WILDFIRE DAMAGE FROM PRE-EXISTING CREMATIONS STORED IN THE HOME

In the extreme, the body will simply be portions of calcined bone, similar to what is produced by a crematorium (Bohnert et al., 1998) before the normal pulverization process that is done to produce the "ash" normally associated with cremation. Bone morphology will be evident on some portions, but there will be large quantities of fragmented long bones and ribs that cannot be identified as to exact location. It is the presence of these larger fragments that allow separation of recent victims from the professionally cremated remains that people often retain in their homes. The latter has been extensively pulverized after cremation to produce a fine-grained material (Warren & Maples, 1997; Warren & Schultz 2002).

10.7 CONCLUSION

There are many assumptions as to what to expect when searching for bodies after a devastating fire. Often people think there will be a charred corpse or that the body has been completely reduced to ash. Instead, the burning process for human bodies is a lengthy and complex process involving both external sources of fuel and consumption of the internal fuels long often long after external sources are depleted.

Understanding how bodies burn allows for refinement of the search process and may help reduce the number of false-positive finds. When the deployment of search personnel requires both effectiveness and efficiency, adjusting expectations will allow for a quick review of areas, using greater critical separation during the search, where bodies should be obvious and a more careful assessment of areas where burning is more complete.

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