CHAPTER 13

Analysis of Skeletal Trauma

13.1 Principles of trauma analysis

The analysis of trauma and other alterations to the skeleton by forensic anthropologists can help answer important questions, including those that might be related to the circumstances of death or could facilitate personal identification. An **alteration** is any change to the physical properties of a bone, while **trauma** refers to the physical disruption of living tissues by outside forces. The conclusions reached from the analysis of skeletal trauma typically include the *timing* of the trauma relative to the death event, and the *mechanism* or type of force that caused the trauma. Trauma timing can be categorized as **antemortem** (occurring before death) or **perimortem** (occurring around the time of death). **Postmortem** alterations are not considered trauma (because by definition they no longer disrupt *living* tissue) but will also be addressed in this chapter. Trauma mechanism is usually categorized as blunt force, high velocity projectile, sharp force, thermal, or some combination of these categories.

Trauma analysis in forensic anthropology is a rather recent development. It was not until the 1980s that anthropologists began to routinely consult on skeletal trauma, but today it is a standard part of forensic anthropological examinations. Trauma analysis should involve careful observation, thorough documentation, and cautious interpretation. When analyzing trauma on skeletonized remains, definitive conclusions are not always possible, and in some cases it is best to simply describe the alterations that are observed. Interpreting traumatic alterations to bone requires knowledge and application of a variety of scientific principles, including those relating to physics, biomechanics, and engineering. While a thorough discussion of bone biomechanics is beyond the scope of this text, some basic principles will be presented in the following section. Readers interested in more technical aspects of bone biomechanics are directed to Cowin (2001) and Martin et al. (1998).

13.2 Forces, bone biomechanics, and fractures

Skeletal trauma often results from the application of **force**, or the action of one object on another. The science that deals with the effects of forces on objects is called **mechanics**, and bones are physical objects that obey mechanical laws (Cowin, 2001) (Box 13.1). This relationship between force and deformation is one of the primary

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BOX 13.1 MECHANICAL LAWS

The primary laws that concern deformable objects such as bone are the laws of motion (Newton, 1687) and the law of elasticity of solid materials (Hooke, 1678). Three Newtonian laws form the basis of classical mechanics:

1) A body remains at rest or moves at a constant speed in a straight line unless acted upon by a force.
2) The force acting on a body is equal to the mass of the body multiplied by its acceleration ($f = ma$).
3) If a body exerts a force on a second body, the second body exerts a force on the first body that is equal in magnitude and opposite in direction to the first force.

Hooke's law states that there is a relationship between the force and deformation of a solid object.

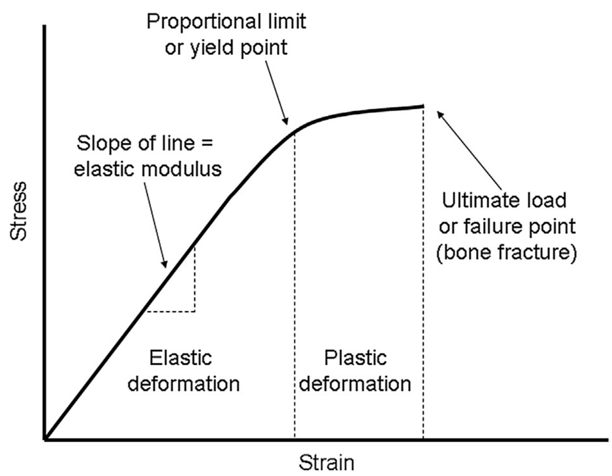


FIGURE 13.1 Young's modulus showing the relationship of stress and strain and their effect on bone deformation and fracture

principles in understanding bone fracture mechanics. For normal **loading** (the application of force to an object), a material's intrinsic **stiffness** (or the ability to resist deformation) is known as the **elastic modulus** or **Young's modulus**. Bone's reaction to loading can be visualized as a load-deformation curve, showing a material's response to force as a function of **stress** and **strain** (Figure 13.1), where stress is the load per unit area, strain is the change in dimension (relative deformation) of a loaded body (Martin et al., 1998), and the slope of the line represents the elastic modulus. Strain in bone has been reported to rarely exceed about 3% (Currey, 1970).

Load and deformation are linearly proportional until the proportional limit or **yield point** is reached, at which point the slope is reduced. When acted upon by a force less than the yield point, bone will react through **elastic deformation**. Elastic deformation is temporary because the bonds between atoms are not broken or irreversibly

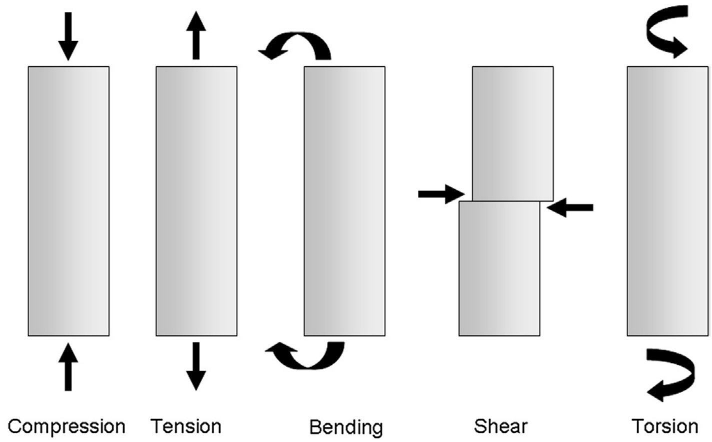


FIGURE 13.2 Types of directional forces affecting bone

deformed, and when the force is no longer applied, the bone will go back to its original shape. With greater force (stress), the bone will reach the yield point after which it will respond through **plastic deformation**, which causes a permanent change to the bone structure. With increasing load, the ultimate load (**failure**) is eventually reached, and it is at this point that **fracture** occurs. The load at the failure point corresponds to a bone's **strength.** The area under the curve is a measure of the amount of total energy needed to cause a fracture, and corresponds to the material's energy absorption or **toughness.** Toughness is an important bone biomechanical property because a tough bone is more resistant to fracture even though it may be less resistant to yielding. Deformation and fracture in bone can be observed at both the microscopic and macroscopic levels (Berryman and Symes, 1998; Smith et al., 2003).

The effect of force on skeletal material is dependent upon both extrinsic and intrinsic factors. Extrinsic factors include the direction, magnitude, and the rate at which the force is applied (Berryman and Symes, 1998). The primary directional forces that affect bone are compression, tension, bending, shear, and torsion (Figure 13.2) (note that compression, tension, and shear are considered "pure" forces while the others are combinations of these forces). **Compression** is a force acting to decrease the dimension of the bone in the direction of the applied force (i.e., "squeeze" the bone). **Tension** is a force acting to increase the dimension of the bone in the direction of the force (i.e., "stretch" the bone). In **bending**, one side of the bone (the concave side) is subjected to a compressive force, while the other side (the convex side) is subjected to a tensile force (often creating shear force). **Shear** is a force that acts to slide portions of the bone relative to one another, parallel to the direction of force. **Torsion** is a force involving a combination of shear and rotation or twisting.

Understanding these forces is important because the strength of a material varies with the direction of force. For example, most materials are weaker in shear than in compression. Bone is stronger under compression than in tension, so fractures typically initiate on surfaces under tension. Even in the absence of external traumatic forces, bones in living vertebrates are continually subjected to a variety of forces arising from gravity, body movements, impacts, and other forces exerted on the skeleton by the viscera (Evans, 1973).

Magnitude refers to the amount of force applied. Typically, the greater the magnitude of force, the greater the severity of the fracture will be. The surface area over which the force is applied will also affect how bone responds to a certain magnitude of force. Bone will be better able to resist deformation in response to the same amount of force applied over a large surface area versus a small surface area because the greater the surface area, the less the force per unit area.

The rate at which force is applied, which relates to the rate of absorption of the force's energy, is also an important factor affecting how bone fractures (Evans, 1973). Force may be applied as either **dynamic** or **static** loading. Dynamic loading refers to a force that is applied suddenly and at relatively high speed. This type of loading is most often responsible for fractures seen in forensic contexts. Static loading is a low-speed force, applied slowly. Bone can support a greater load before failure if the load is applied slowly rather than rapidly (Evans, 1973).

Even stress applied at levels below the failure point can cause fractures due to either time-dependent or cycle-dependent loading (Caler and Carter, 1989; Evans, 1973). If a relatively low static force is applied over an extended period of time, the bone may continue to deform and fracture; such fractures are called **creep fractures** (Caler and Carter 1989; Galloway, 1999). Repetitive loading at pre-failure forces can eventually degrade the mechanical properties of bone by causing small cracks in the bone which will eventually grow and coalesce, causing failure; such fractures are called **fatigue fractures** (Turner and Burr, 1993), or "stress fractures." The fatigue strength of bone has been shown to be far less than its static strength (Agarwal and Broutman, 1980).

The effect that forces have on bone also depends on a number of intrinsic factors that affect the ability of bone to resist deformation and failure including its composition, cross-sectional area, and geometry. Many biological materials, including bone, have a "grain," or an internal organized structure that is not the same in all directions (recall from Chapter 2 that the general orientation of bone structure is in the longitudinal direction; wood is another example of a material with a grain). Because of this, bone does not have the same structural properties in all directions. Materials that have the same properties in all directions (such as steel) are called **isotropic**. Materials like bone that have different properties in different directions are called **anisotropic**. Human osteonal bone is actually considered transversely isotropic because it has the same properties in all transverse directions, but has different properties in the longitudinal direction (Reilly and Burstein, 1975).

Bone composition, area, and geometry vary between the sexes and across populations, and can also change over time or in association with certain pathological conditions. This means that there are often population-, age-, and pathology-related differences in bone strength and stiffness. Age-related decreases in bone density such as osteoporosis or osteomalacia can affect bone's mechanical properties, as can skeletal diseases such as osteogenesis imperfecta or rickets. Diet and mechanical loading also affect bone's biomechanical properties.

It is also important to note that these forces do not always occur in isolation, and traumatic events affecting bones may involve various types of force. Moreover, these principles apply primarily to cortical bone. Assessment of the mechanical properties of trabecular bone is much more difficult because individual trabeculae each have their own stiffness (material stiffness), and the structure they comprise together has its own stiffness (structural stiffness).

The failure (fracture) of bone under these different forces and loading regimes are varied, and fractures can be classified based on their degree and morphology. The broadest category of fracture is whether it is **incomplete** or **complete**, and fractures can be further categorized by type (Table 13.1). Incomplete fractures are those where some continuity is retained between the fractured bone portions, and these occur more commonly in children due to the greater elasticity of their bones

Table 13.1 Classification of bone fractures

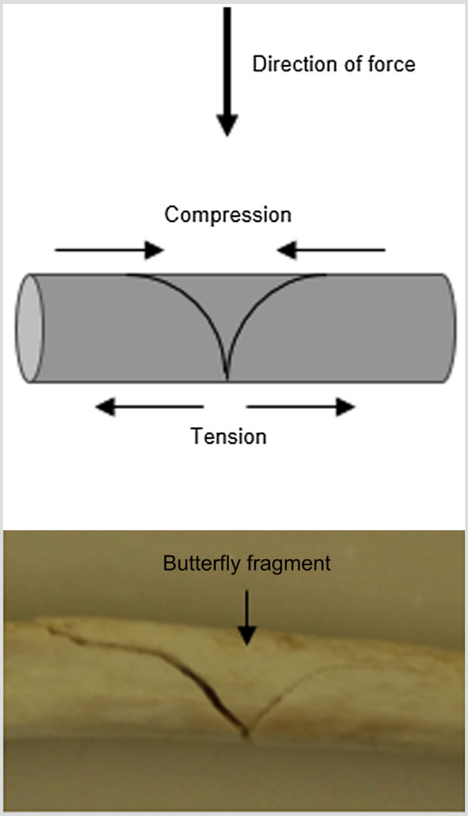
Fracture types		Fracture characteristics
Incomplete fractures	Bow fracture	Fracture with exaggerated curvature along the length of the bone; more common in children
	Torus or buckle fracture	Fracture resulting from buckling of bone cortex due to compressive force; appears as a rounded expansion of the bone
	Greenstick fracture	Fracture resulting from bending or angulation forces on one side and compression on the other; appears as a transverse fracture with fractures deviating at right angles along the long axis of the bone
	Depressed fracture	Fracture resulting in a "caving in" of the bone; occurs primarily in the skull
Complete fractures	Transverse fracture	Fracture occurring at approximate right angles to the long axis of the bone; typically from blunt trauma directed perpendicular to the shaft
	Oblique fracture	Fracture running diagonally across the diaphysis; usually the result of a combination of angulation and compressive force
	Spiral fracture	Fracture that circles the shaft, usually from rotational forces
	Comminuted fracture	Fracture in which more than two fragments are generated; usually resulting from relatively high levels of force; butterfly and segmental are types of comminuted fracture
	Epiphyseal fracture	Fracture involving the growth plate; such fractures may be limited to the cartilage, but may also involve the surrounding bone

(Modified from Galloway, 1999 and Gozna, 1982)

(Rogers, 1978). Complete fractures are those in which there is discontinuity between two or more bone fragments. Whether a fracture is complete or incomplete is often dependent on the magnitude and direction of force. For example, comminuted fractures tend to be associated with greater magnitude forces, and butterfly fractures (Box 13.2) tend to result from bending. Categorization of

BOX 13.2 BUTTERFLY FRACTURES

Butterfly fractures are comminuted fractures that result from bending forces which create tension on one side of the bone and compression on the other. The bone fails first on the surface under tension (the convex side of the bend), and oblique transverse fractures (usually bilateral) due to shear forces then propagate toward the surface under compression (the concave side of the bend). The result is often a dissociated triangular "butterfly fragment." It is often possible to determine the direction of the force based on the directionality of this butterfly fragment. The impact is typically on the compression side, with the fracture initiating on the opposing tension side. Butterfly fragments were long thought to be produced by force applied to the tension side, resulting in the misinterpretation of the direction of the applied force. Butterfly fractures are commonly seen in motor vehicle-pedestrian victims where the bumper impacts the legs. The butterfly fragment can be useful in interpreting which direction the pedestrian was facing when struck.



fracture type (which is common in biomechanics) may be part of a skeletal trauma analysis, but typological systems are usually too vague to account for all aspects of the trauma event. A thorough skeletal trauma analysis should also involve an interpretation the trauma event including the forces involved and directionality.

13.3 Trauma timing

Trauma timing can be categorized according to when it occurred relative to the death event. Antemortem trauma is an alteration produced before an individual's death. The primary evidence of antemortem trauma is **osteogenic reaction** (or the formation of new bone) since, naturally, such responses will only occur if an individual is still alive. Osteogenic reaction is usually in the form of fracture healing (Box 13.3) or infectious response. Fracture healing may be evidenced by rounded fracture edges or a fracture callus (Figure 13.3). Infectious response may be evidenced by proliferative or lytic lesions.

Although the identification of antemortem trauma typically eliminates that injury from being directly related to the death event, certain antemortem trauma patterns can indicate a particular injury history (such as a major accident, a history of abuse, or human rights violations) which may provide clues regarding possible causes of death, or may have indirectly contributed to the death. In addition, the presence of antemortem trauma in unidentified skeletal remains serves as information that can be useful in the identification process (see Chapter 14).

BOX 13.3 STAGES OF FRACTURE REPAIR

Fracture repair occurs in three primary stages. The first stage is the reactive or inflammation stage, which occurs during the first few days following a fracture. First, bleeding occurs due to the broken blood vessels near the fracture site. This blood often pools in the adjacent area, forming a **hematoma**. **Inflammation** also occurs as the body increases the amount of plasma and white blood cells in the injured area to facilitate healing. Osteoclasts work in fracture sites to resorb dead bone which may appear radiographically as a blurring of the fracture margin and widening of the fracture gap (Rogers, 1992). Fractures also stimulate osteoid formation within the first few days to begin to bridge the broken surfaces and repair the fracture. This osteoid formation may not be immediately obvious in an anthropological examination (Barbian and Sledzik, 2008). It may not be visible to the naked eye or radiographically, and may require microscopy or histology to detect. Histologically, new bone formation can be seen by approximately 5–7 days as spicules of woven bone, but these spicules are delicate and may be lost if the body is completely skeletonized.

The second stage of fracture healing is the reparative stage, which occurs over the following weeks and months. Within the first few weeks, a soft **fracture callus** of fibrous bone forms, building on the framework of the deposited osteoid. This becomes a hard callus by 6–12 weeks, and eventually clinical union of bone is reached. Calluses are typically quite visible during gross examination and radiographically due to their raised appearance and lower bone quality.

The third and final stage of fracture repair is the remodeling stage, which occurs months to years following the fracture, and involves remodeling of the quickly deposited bone at the fracture site. In the early remodeling stages, the fracture callus may still be visible, but after years of remodeling, the fracture site may become difficult to detect.

FIGURE 13.3 Healed fracture (antemortem trauma) on a femur

(Photo by Rebecca Meeusen; specimen courtesy of the National Museum of Natural History)

Other antemortem alterations in which bone remodeling processes are observed include healing from surgical procedures such as trephination (Figure 13.4) as well as the resorption or filling in of the vacant alveolar space when teeth are lost or extracted (Figure 13.5). This resorption usually takes several months following tooth loss. When all teeth have been lost with complete resorption of the alveolar space, the individual is considered **edentulous**.

Perimortem trauma refers to an injury that occurred relatively near the time of death. Because of the varying temporal specificity associated with this term when used by practitioners in different fields, it requires a more detailed explanation. When a forensic pathologist, for example, uses the term "perimortem," they typically mean within

FIGURE 13.4 Trephination

(Photo by Rebecca Meeusen; specimen courtesy of the National Museum of Natural History)

a very short time period surrounding death (e.g., seconds or minutes) and directly related to the death event. This level of specificity is often possible when evaluating trauma to the soft tissues. Skeletal alterations, however, cannot usually be timed so precisely. Perimortem trauma to bone is best defined as those injuries that occur when the bone is in a biomechanically fresh state; that is, when it retains components and properties that make it fracture in the same mechanical manner as viable bone. This means that the perimortem interval for forensic anthropological assessments could be quite long and extend relatively far (months, for example) into the postmortem period, as long as the bone is still in a fresh state when the fracture occurred. Because of these different temporal meanings, when the term "perimortem" is used, it should be clearly explained and accompanied by a justification for the classification.

Various fracture characteristics are typical of biomechanically fresh bone. Evidence of perimortem trauma to bone includes plastic deformation (Figure 13.6), hinge fractures, and staining on the bone associated with a hematoma. The presence of small bone fragments adherent to adjacent fractured bone also suggests perimortem trauma (Ortner and Putschar, 1985). By comparison to antemortem fractures, perimortem fractures will lack evidence of healing or infectious response. Compared to postmortem fractures, fresh bone fractures are often more straight whereas dry bone fractures tend to have a more jagged appearance. Another indicator of

FIGURE 13.5 Edentulous mandible. Resorption of the alveolar bone indicates that tooth loss was an antemortem process

(Photo by Rebecca Meeusen; specimen courtesy of the National Museum of Natural History)

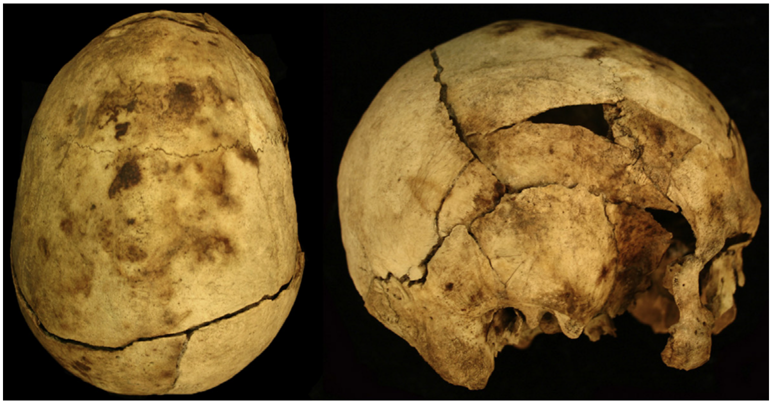


FIGURE 13.6 Perimortem trauma with associated plastic deformation; note how the fragments cannot all be refitted along their edges due to changes in bone shape

perimortem trauma is an overall fracture pattern that is characteristic of a terminal event (Scientific Working Group for Forensic Anthropology [SWGANTH], 2011; Moraitis et al., 2009) such as a gunshot wound or fall from a great height.

Postmortem damage refers to taphonomic alterations to bone that are produced after death and that are unassociated with the death event. In some cases, postmortem damage may be *related* to the death event (for example, mutilation or

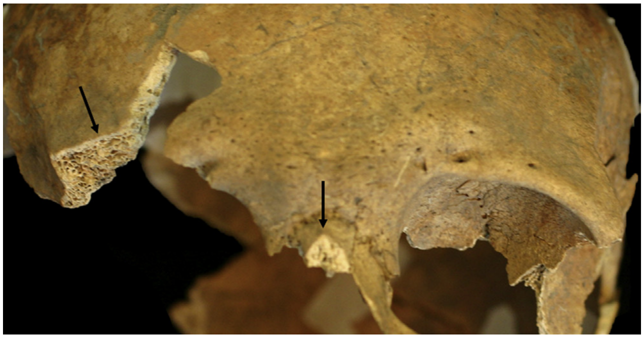


FIGURE 13.7 Postmortem damage to cranium; note the lighter color of the recently exposed surfaces

dismemberment inflicted by a perpetrator after a homicide), but in most cases, the analysis of postmortem bone alteration technically falls under taphonomic analysis (see Chapter 5). Postmortem damage can sometimes be distinguished from perimortem trauma by differential staining, such as where perimortem fracture edges are stained by hemorrhage, decomposition fluids, soil, or other materials. The fracture edges of postmortem damaged bones will often be lighter than the surrounding bone because these surfaces are exposed to the environment at a later time (Figure 13.7). Like perimortem trauma, postmortem damage will not show evidence of healing. An overall pattern of damage consistent with known postmortem causes such as animal scavenging patterns can also differentiate the damage from perimortem trauma. In long bones, postmortem breaks will tend to occur at right angles to the long axis of the bone. Although assessment of fractures can yield clues that can differentiate postmortem damage from perimortem trauma, several factors can complicate differentiation of postmortem and perimortem alterations. These include abrasive modification that can round fracture edges, sun exposure and bleaching which can alter previous coloration differences, and other destructive postmortem alterations such as scavenging that can obscure or destroy the perimortem trauma.

Biomechanically, the reason postmortem fractures differ is because dry bone responds to force differently than fresh bone. Living bone contains moisture and collagen, which give it greater elasticity. When bone dries, its elastic modulus and strength will actually increase, but its toughness will decrease (Turner and Burr, 1993). While the stress must be greater to cause dry bones to fracture, they can absorb less energy prior to failure. One study demonstrated that a dried human femur showed a 17% increase in Young's modulus and a 31% increase in tensile strength, but a 55% decrease in toughness (Evans and Lebow, 1951). In addition, fresh bone contains water, which acts to absorb and dissipate some energy (a property called **viscoelasticity**). When bone is dry, it no longer has this energy-absorbing quality, so the mechanical properties are altered and it behaves more like an inorganic material. This response is similar to the way a dried out branch or twig that has lost its moisture content will snap, while a green stick will have more flexibility.

13.4 Trauma mechanism

Trauma mechanism refers to the way force was applied to the bone, resulting in the alteration. Trauma mechanism is typically classified as being the result of blunt force, high velocity projectile, sharp force, thermal, or some combination, and is usually determined by examination of the overall pattern of alteration. It is important to note, however, that although these categories can be descriptive and helpful, the forces that produce skeletal trauma occur along a continuum and not in discrete categories. For example, the difference between blunt trauma and some types of sharp trauma is the area of impact, with sharp trauma resulting from a force applied by a tool with very small surface area. The difference between blunt trauma and high velocity projectile trauma is the rate at which the force is applied, with high velocity projectile trauma resulting from a force applied by an object moving at a very high rate of speed and impacting a small surface area. At their extremes, trauma mechanisms are often more apparent, but they can sometimes be difficult to discern. Reconstruction of fractured bone fragments (see Chapter 7) is frequently necessary in order to observe the overall pattern of trauma, especially in cases with a large amount of fragmentation.

Blunt force trauma

Blunt force trauma results from (relatively) slow load application to bone (Passalacqua and Fenton, 2012; Berryman and Symes, 1998) over a relatively large surface area. Such traumas may result from a blow from an object (such as a club, hammer, or fist), but also include deceleration injuries such as transportation accidents and falls from heights. Blunt force traumas are usually interpreted by their fracture patterns.

Fractures from blunt force trauma will follow the path of least resistance, propagating until the energy has dissipated. In the cranium, fractures will often terminate into one of the cranial sutures which dissipate the fracture energy; greater amounts of force are typically involved in fractures that continue through sutures. Certain parts of the skeleton, especially in the cranium, have areas that are more reinforced (a characteristic referred to as **buttressing**) which also helps redirect forces and dissipate stress. Certain fracture patterns of the facial skeleton are fairly well understood and documented in relation to these facial buttresses. The patterns are a product of relative strengths of certain areas of the facial skeleton (Rogers, 1982), and are characterized by LeFort fractures (Figure 13.8). LeFort I (or horizontal) fractures involve the alveolar portion of the maxillae and inferior nasal aperture, and typically result from force applied to the lower face. LeFort II (or pyramidal) fractures involve the nasal bridge, lower borders of the orbits, and posterior maxillae, and typically result from force applied to the midface. LeFort III (or transverse) fractures involve the medial walls of the orbits and the zygomatics, and typically result from force applied to the nasal bridge or upper maxilla.

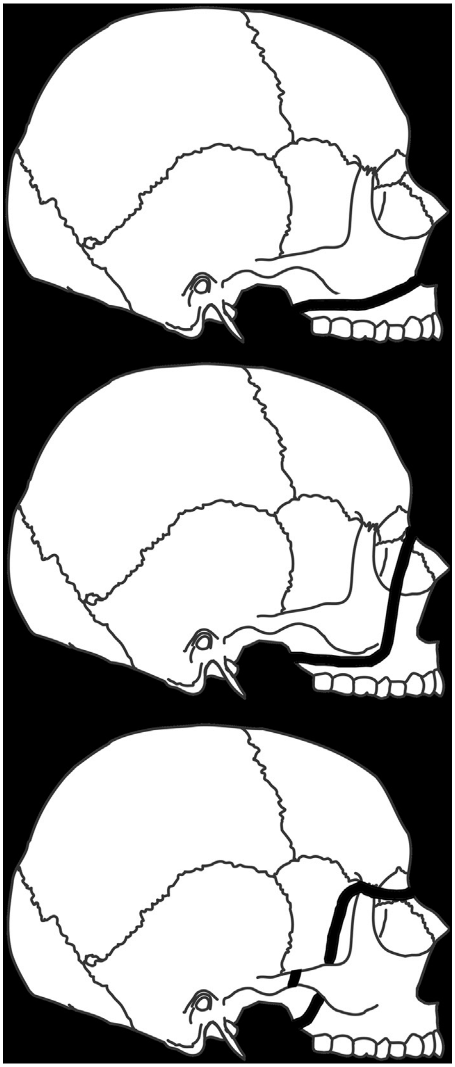


FIGURE 13.8 LeFort fractures: LeFort I (top), LeFort II (center), and Lefort III (bottom)

In blunt force trauma to the cranial vault, the bone typically bends internally, creating tensile stress on the inner table. This internal tensile stress causes fractures which start at the inner table, but often continue through to the outer table and radiate outward from the impact site, creating a pattern of **radiating fractures**. If the object continues inward on the skull, **concentric fractures** (which are collapsing the bone inwardly) may also form, circumscribing the impact site (Figure 13.9).

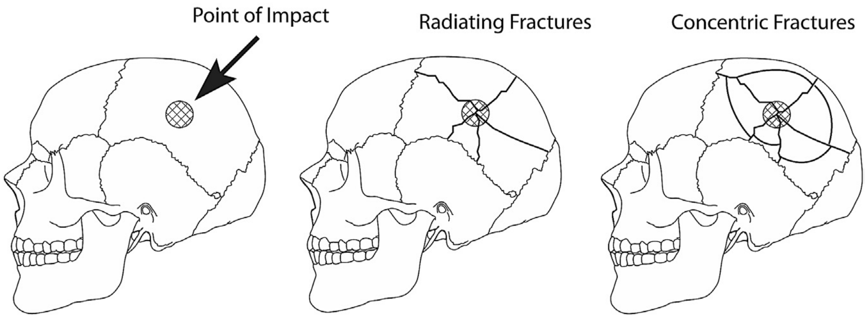


FIGURE 13.9 Blunt force trauma impact with radiating and concentric fractures

FIGURE 13.10 Blunt trauma with tool impression

Characteristics of blunt trauma include plastic deformation, **delamination**, patterns from known blunt causes (such as falls from heights), and tool marks or impressions (Scientific Working Group for Forensic Anthropology [SWGANTH], 2011) (Figure 13.10). Because of the slow loading nature of blunt force trauma, there is time for the bone to bend, which results in a permanent deformation of the material. When an implement or

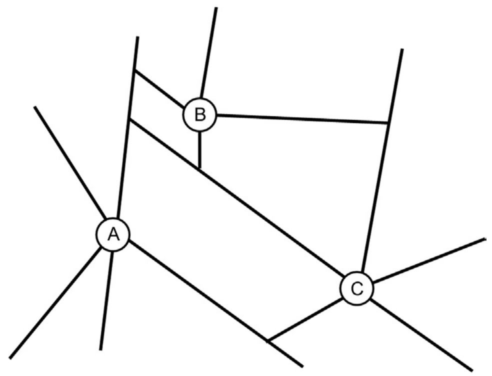


FIGURE 13.11 Determination of sequence of trauma events. The impacts occurred in the following sequence: A-C-B

tool is used to inflict blunt force trauma, the size and shape of the wound or impressions from tool features may give clues about the tool class and direction of impact.

In cases of multiple blunt impacts, it may be possible to determine the sequence in which the impacts occurred. Fractures from an impact will propagate until the energy has dissipated or until they encounter a discontinuity in the bone through which the energy is dissipated. This means that fractures from subsequent impacts will terminate into fractures from pre-existing impacts. In Figure 13.11, for example, the fractures originating from impact "A" do not terminate into any of the other fractures. The fractures from impact "B" terminate into fractures from impacts "A" and "C." Fractures from impact "C" terminate into fractures from impact "A." The sequence of the impacts is therefore A, then C, and then B.

Another form of blunt trauma is the slow application of force through compression of the neck as is seen in cases of strangulation (either manual or using a ligature) or hanging (which may be related to a suicide, homicide, or judicial hangings). Perimortem hyoid fractures (Figure 13.12) have been noted to indicate manual strangulation, although other forms of neck trauma cannot be excluded without further investigation (Ubelaker, 1992). Apparent hyoid fractures should be examined carefully, however, because unfused or incompletely ossified hyoids can easily be mistaken for traumatic separation. Hyoid fractures are more likely to occur in older individuals where ossification of the hyoid is more complete (Pollanen and Chiasson, 1996). Hyoids are not always fractured in cases of compressive trauma to the neck, and the absence of hyoid fractures does not mean that strangulation or neck compression can be excluded (Pollanen and Chiasson, 1996). Hangings, which usually produce more force on the neck than strangulation, can also result in fractures of the cervical vertebrae, especially the bilateral fracture of the pedicles of C2. These are referred to as a **hangman's fracture**, though these fractures do not always occur in judicial hangings (James and Nasmyth-Jones, 1992), and are also commonly associated with other causes such as motor vehicle accidents or sports-related injuries.

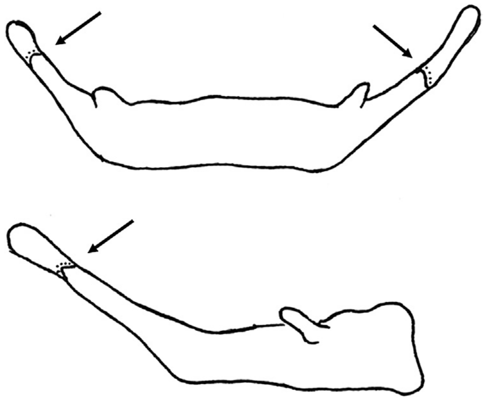


FIGURE 13.12 Fractures of the hyoid which likely resulted from strangulation or hanging; anterior (top) and lateral (bottom) views

High velocity projectile trauma

High velocity projectile trauma is characterized by a very rapid application of force over a relatively small surface area. Typically these wounds are produced by bullets from firearms (which travel at speeds of ~1100–4000 feet/second), but may also result from shrapnel from a blast or any other very fast-moving small object. This type of trauma is sometimes referred to as *ballistic trauma*, but the term **ballistic** technically refers to bullets in flight or the internal actions of firearms, and not to the actual force that resulted in the trauma. The term *high velocity projectile* is also more inclusive since not all high velocity projectile traumas are caused by bullets. Note that other projectiles such as thrown javelins or arrows (which travel at ~300 feet/second), are not considered high velocity projectiles, and the resulting alterations would therefore be categorized as blunt force trauma. High velocity projectile trauma can usually be recognized by the fracture characteristics, and shape and size of the wound/s, as well as associated beveling and fractures.

Most high velocity projectile wounds are relatively round, but they may also be oval, keyhole-shaped, or irregularly shaped. Round wounds are commonly seen in cases where the impact of the projectile is roughly perpendicular to the surface of the bone. When the projectile trajectory is not perpendicular, the wounds are more likely to be oval or keyhole-shaped. The more extreme the angle (i.e., the more tangential the trajectory), the more likely a keyhole-shaped defect is to occur (Figures 13.13 and 13.14).

The size of the projectile wound is related to various factors, including characteristics of the projectile (its size, how it is constructed, and how fast it is moving) and characteristics of the bone (such as whether it is a flat or tubular bone). While the size of a projectile (such as the *caliber* or size of a bullet) is often roughly correlated with the size of the wound, bone is a material that deforms when force is applied, and the wound may not be a true representation of the projectile size. For bullets, for

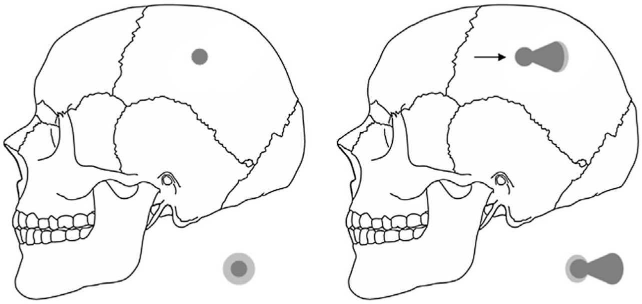


FIGURE 13.13 High velocity projectile defect shapes

Left: A round defect is typically produced when the projectile enters perpendicular to the bone. Right: A keyhole-shaped defect is typically produced when the projectile contacts the bone at an angle. Dark areas indicate missing bone and light areas indicated exposed diploë/beveling. Arrow indicates direction of projectile path; bottom wound patterns represent internal views.

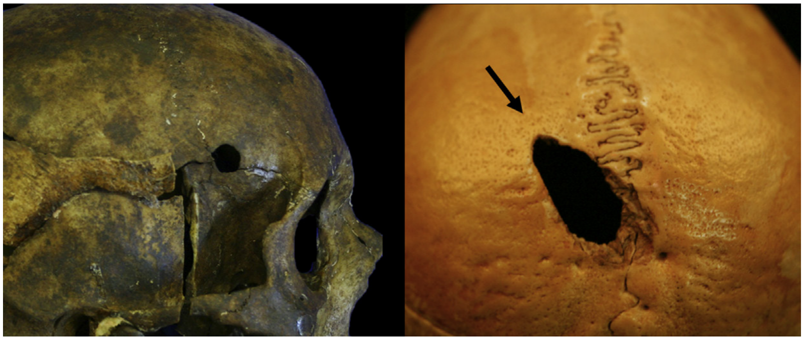


FIGURE 13.14 Round entrance defect (left) and keyhole entrance defect (right)

example, only the relative caliber size (i.e., large caliber versus small caliber) can usually be determined (Berryman et al., 1995; Ross, 1996).

One characteristic of high velocity projectile trauma is **beveling**, or angling of the alteration in the direction of the projectile, especially on flat bones such as those of the cranial vault. Beveling is the result of plug-and-spall fractures caused by fast-moving objects (Figure 13.15). As a high velocity projectile passes through bone, a plug of bone in the projectile's path is displaced. Spall refers to small flakes of bone that are broken off when the projectile penetrates the other side of the bone. The result is that the side of the bone where the projectile exits has a greater extent of missing bone than the side where the projectile enters. Entrance wounds are therefore typically internally beveled while exit wounds are externally beveled (Figure 13.16). The direction and path of a projectile can often be deduced from beveling characteristics.

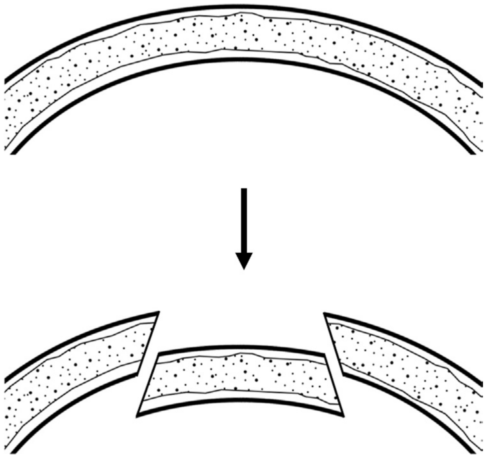


FIGURE 13.15 Beveling from plug-and-spall; arrow indicates direction of projectile

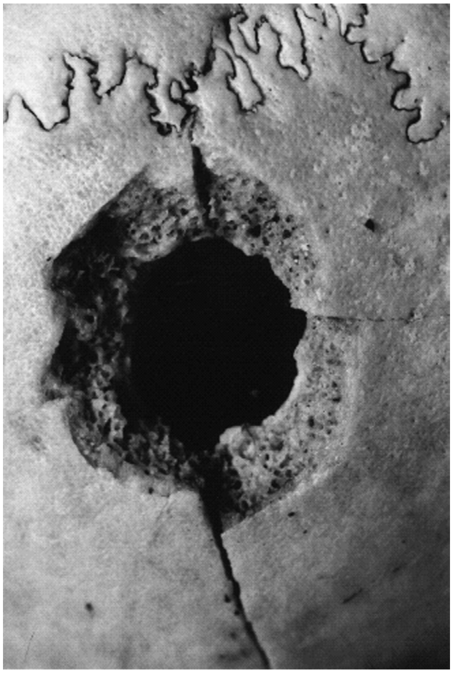


FIGURE 13.16 External beveling of a cranial projectile exit wound

(From Ross, n.d.)

Similarly to blunt trauma, high velocity projectile trauma occurring on the cranial vault often results in two common types of fractures, radiating and concentric (Figure 13.17). Radiating fractures are linear fractures that radiate out from the impact site, and concentric fractures are curved or circular lines that surround the impact site. In

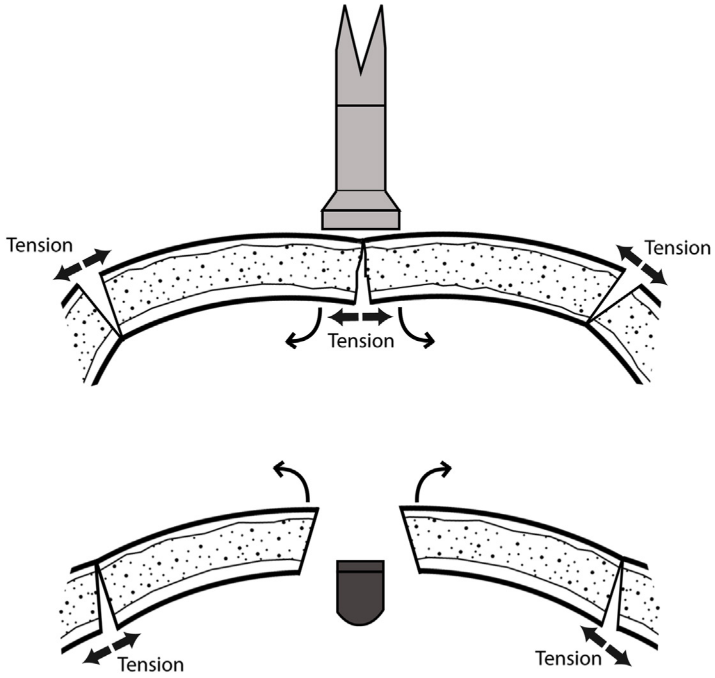


FIGURE 13.17 Comparison of concentric cranial fractures in blunt force (top) and high velocity projectile (bottom) traumas. Blunt force concentric fractures cave the bone in, while high velocity projectile fractures push the bone out

contrast to the collapsing concentric fractures produced in blunt force trauma, which tend to be internally beveled, the concentric fractures associated with high velocity projectile trauma tend to be externally beveled because they are heaving outward from intracranial pressure caused by the bullet passing through the brain (Smith et al., 1987).

Little or no plastic deformation is associated with high velocity projectile trauma because the force is applied so rapidly that the bone does not have time to bend and deform. Additionally, because of the magnitude of the force, high velocity projectile traumas also tend to result in a greater degree of fracturing and fragmentation than other traumas.

Even in the absence of a recognizable injury pattern, the involvement of a projectile may be evident from remnants of the projectile left behind and visible in radiographs (Figure 13.18). Recall from Chapter 3 that certain materials will stand out in radiographs due to their relative radiodensities. Projectiles are typically constructed of metals which are more radiodense than bone and will appear distinct from bone radiographically. In some cases, fragments of the projectile may be present within the cranium, and sometimes even if the projectile has passed all the way through the bone, small remnants of the projectile may have been deposited on the bone as they made contact (often called “lead wipe”) which will also be visible in radiographs. Pellets

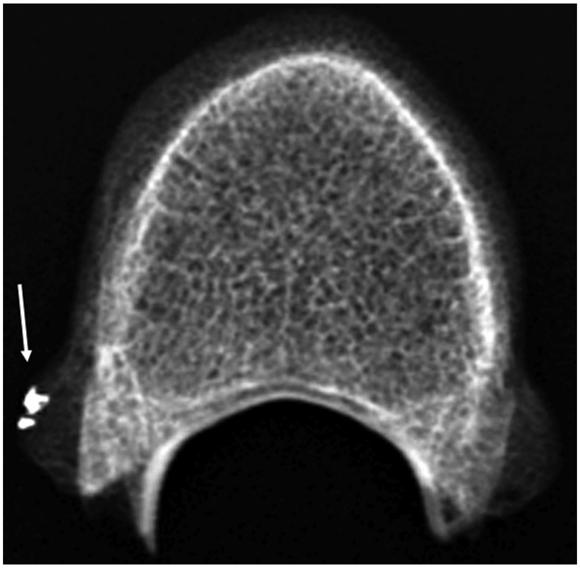


FIGURE 13.18 Projectile fragments visible in a radiograph of a vertebra

from shotgun wounds usually do not have enough remaining force to exit the body, and can often be located using radiography either within soft tissues or embedded in bone.

Multiple projectile wounds can often be sequenced similarly to blunt force trauma impacts on the basis of fracture patterns. It is important to note, however, that fractures can travel though bone at an extremely high speed, and it is possible for radiating fractures from an entrance wound to reach the other side of the cranial vault before the projectile exits the cranium.

Sharp force trauma

Sharp force trauma is characterized as trauma created by a tool with a point or beveled edge (Symes et al. 1998, 2002; DiMaio and DiMaio, 2001; Spitz, 1993). Sharp force trauma often occurs under loading conditions similar to blunt force trauma, but using a tool with a very small surface area (e.g., the edge of a blade). Sharp force traumas often leave distinctive marks (cuts) on the bone. While sharp force traumas can be caused by a wide variety of implements, two commonly utilized and heavily researched tools are knives and saws. Functionally, the purpose of a knife is to cut soft material, while a saw is designed to cut hard material and they therefore function rather differently. Knives typically have a narrow beveled edge which comes back to a wide **spine**. Saws have wide teeth which come back to a relatively narrow spine (Figure 13.19) so that they will not bind when cutting through hard material.

Knife cuts and stab wounds typically leave alterations such as straight line incisions, punctures, gouges, and clefts (Figure 13.20). There are two general classes of knives: serrated and non-serrated. Serrated knives have teeth built into the blade,

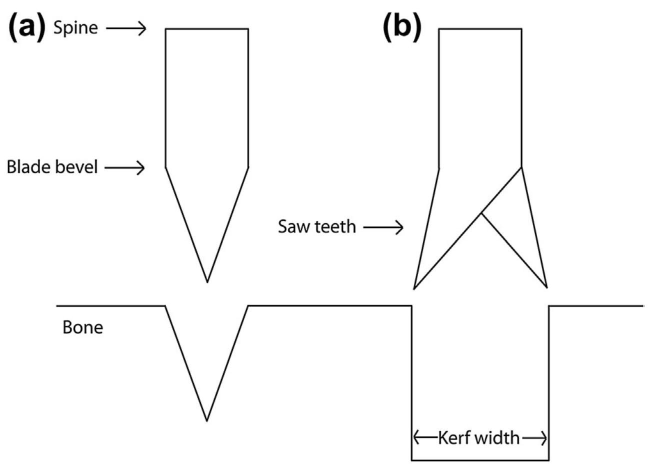


FIGURE 13.19 Cross-sections of a single bladed knife (a), and a cross-cut saw blade (b)

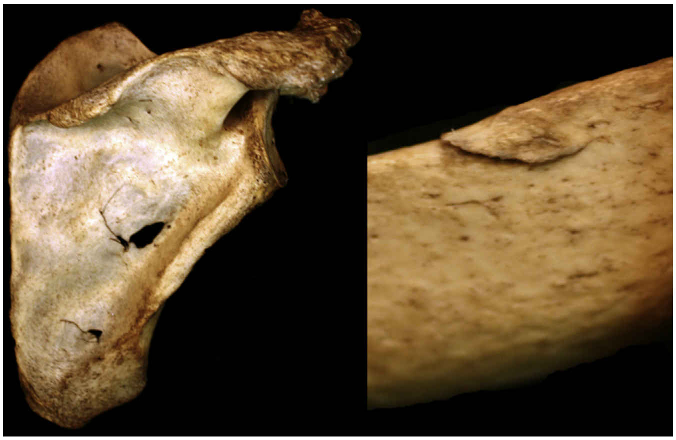


FIGURE 13.20 Knife puncture wounds in a scapula (left) and incised wound in a rib (right)

whereas non-serrated knives have smooth blades. The teeth on serrated blades create striations on bone that are distinctive from non-serrated blades, and can be used to determine the class of the knife used.

Saws consist of teeth which are designed to cut through hard material. As saws progress though material, they create a **kerf**, or groove (Figure 13.21). The marks created by saws can be analyzed to determine the class of the saw used. Class characteristics of saws include such traits as the blade and tooth size and shape, teeth-per-inch, blade and tooth set, cutting action, and saw power (i.e., hand vs. mechanical). The direction of the progress (of the saw cut) as well as the direction of the stroke can also be determined by examining the cut for exit chipping and breakaway spurs (Figure 13.22).

FIGURE 13.21 Kerf marks from a saw on a femur

(from Symes et al., 2010)

FIGURE 13.22 Saw cut marks on a bone

Dismemberment is almost always associated with sharp force trauma on bone. In many cases perpetrators attempt to dismember a body using knives, only to discover that the knives cannot easily cut through bone. It is therefore not uncommon to find both knife and saw marks on dismembered remains, or to have incomplete knife cuts in bones which are then broken at these weakened areas. Bodies are typically dismembered in order to prevent their detection and identification. Dismemberment generally occurs after death which is technically in the postmortem period (in relation to the death event), but is usually performed when bones are still in a biomechanically fresh state; alterations would therefore have the biomechanical properties of perimortem trauma.

It is common in cases of sharp force trauma for forensic anthropologists to work in conjunction with tool mark experts. Forensic anthropologists are typically the ones to discover and locate the trauma on the remains, and focus their examination primarily on classifying trauma type and timing and providing a general description of the skeletal alterations. Tool mark examiners are typically responsible for making more detailed conclusions about the class of tool used and comparing alterations to a particular tool to determine whether it is consistent with having created the alterations observed on the bone.

Thermal alterations

Thermal alterations result from exposure of the body to **fire** or other heat sources. Due to the nature of thermal reactions, the process can be very destructive to the organic material. Early stages of thermal alteration involve the burning of the fleshed human body. With the continued application of the thermal source, the bones may become exposed and damaged as the organic components become fuel for the continuing exothermic reaction. Although some studies have attempted to correlate certain bone alterations with particular temperatures, thermal alterations are a function of both time and temperature. In other words, similar alterations can be produced with high heat over a short period of time or lower heat over a longer period of time.

Understanding the normal burn pattern (e.g., that seen in an unobstructed body under typical burning conditions) can help with interpretations regarding whether any unusual circumstances were at play. The soft tissues are altered first, resulting in a loss of moisture which causes the muscles (typically the larger flexors) and ligaments to contract. As this occurs, the position of the body shifts, resulting is what is referred to as the pugilistic posture (Symes et al., 2008) (Figure 13.23). With continued exposure to heat, the soft tissues will continue to burn. The thickness of the soft tissues plays a large role in the exposure and heat alteration of bone. Skeletal regions with less overlying soft tissue will typically be exposed first, while those areas with more overlying soft tissue will burn last (Figure 13.24).

Understanding the cause and mechanism of the pugilistic posture and general body soft tissue thicknesses allows for burn patterns to be analyzed and abnormal

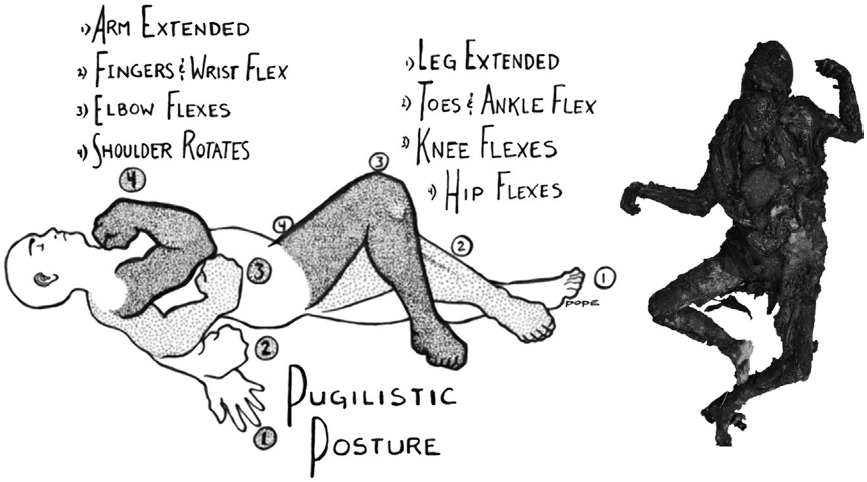


FIGURE 13.23 Pugilistic posture with flexion of the fingers, elbows, toes, knees, and hip

(Images courtesy of Elayne Pope)

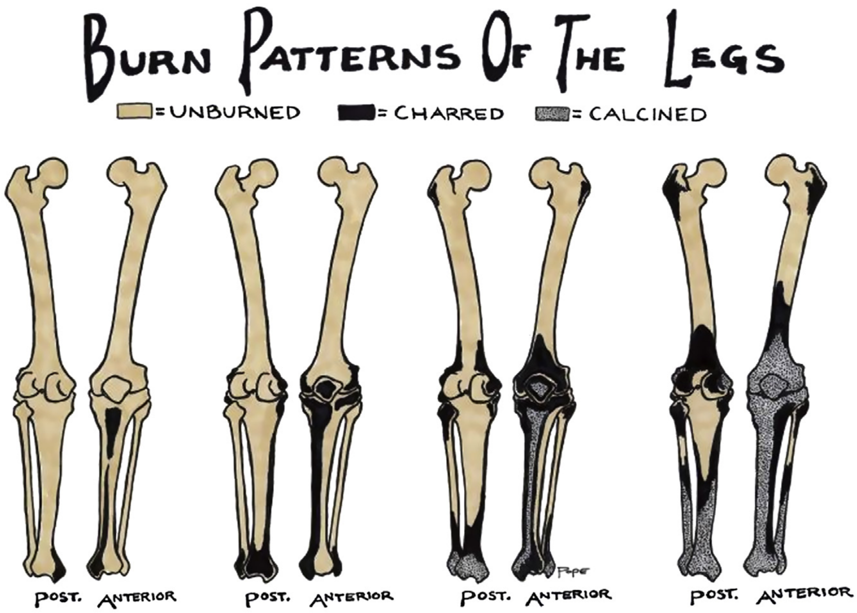


FIGURE 13.24 Burn patterns of the anterior and posterior legs with differential exposure sites of bone in areas of thin soft tissue protection, while other surfaces remain protected by muscle

(Image courtesy of Elayne Pope)

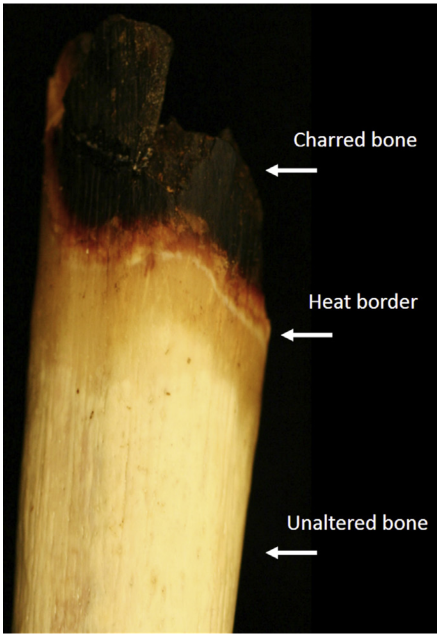


FIGURE 13.25 Color changes in heat-altered bone

burn patterns to become apparent (Symes et al., 2008). For instance, if a body is burned using accelerants or placed in the trunk of a car, the burn patterns will often deviate from the normal pattern. Accelerants may result in a greater amount of burning to areas with thicker soft tissues, resulting in a greater degree of alterations in these areas than otherwise expected. Being placed in the trunk of a car or other confined space may limit the body's ability to assume the pugilistic posture. Thus careful documentation of the fire scene is important in order to fully interpret the burn pattern present on a set of remains (Dirkmaat, 2002).

Once the soft tissues have burned away, the bones become exposed to heat and flames, resulting in thermal alterations to the bone. Heat-altered bone is evident by color changes, shrinkage, fractures, and other physical alterations. Color changes are typically the first to occur in heat-altered bone, with these changes corresponding primarily to changes in the organic component (Figure 13.25). Normal, unheated bone is a pale yellow color. In the very early stages of heat alteration, occurring in areas that are still covered by soft tissues (such that the bone is exposed to heat but not to direct flame, resulting in loss of moisture and some molecular alteration), altered osseous tissue will first appear as a white color, sometimes referred to as the heat border. As thermal exposure continues, the bone becomes darkened in color, eventually becoming black, a condition referred to as **charred**. Charred bone has been directly exposed to fire, and is a result of the carbonization of the organic component of the bone. Eventually, the bone will become **calcined**. Calcined bone has been thermally altered to the extent that it has lost all organic content and moisture. At the calcined stage, the remains are simply a framework of the inorganic components of bone (i.e., hydroxyapatite) and are very fragile.

Table 13.2 Heat-induced fractures

Fracture type	Fracture characteristics
Transverse fracture	Fracture occurring transversely in long bone shafts as a function of the bone structure weakening and failing from heat alteration
Curved transverse fracture	Half-moon shaped fractures which occur in long bone shafts as the soft tissues shrink and pull back from the bone; these fractures are indicative of direction of fire progression
Step fracture	Fractures extending transversely from a longitudinal fracture across a long bone shaft
Patina	Superficial micro-fractures which often have a mesh or spider-web appearance

Thermally-altered bone also decreases in dimension, or shrinks. This shrinkage is a function of the combustion of the organic components of bone and evaporation of water, causing the bone to decrease in overall size. Shrinkage may also be associated with heat-related warping and deformation. These changes in dimensions and overall shape should be considered in laboratory analysis since they could affect metric analyses such as those used to estimate sex and stature.

Another effect of heat on bone is fractures. Burned bone fractures share many characteristics with other postmortem dry bone fractures in that they have sharp (rather than smooth) margins and they often occur along the grain of the bone (longitudinally). Burned bone also fractures in response to soft tissue shrinkage and the direction of fire progression, resulting in fractures that are specific to heat-altered bone. Heat-induced fractures include transverse, curved transverse (thumbnail), step, and patina (Table 13.2 and Figure 13.26). Similar heat-induced fractures occur in the dentition as well (Schmidt, 2008). In crania, there is often delamination of the outer bone layer (Figure 13.27).

Heat alterations to skeletal tissues are also apparent at the microscopic level. With the application of heat of increasing temperatures, tissues (including both bones and teeth) first show an increase in surface roughness, then becoming glassy and smooth, then acquiring a frothy appearance, and finally protuberances coalesce into smooth-surfaced nodules (Shipman et al., 1984). Increasing temperature is also associated with an increase in mineral crystal size (Shipman et al., 1984).

Cremation is an extreme form of thermal alteration where the body is reduced to bone that is completely calcined and disintegrates to ash (Figure 13.28). Cremation can occur as a part of funerary practices, it may be performed intentionally as a criminal act to dispose of a body, or it may be accidental such as in a structure fire. In modern commercial cremation, remains are placed into a furnace called a **retort** where they are burned at high temperatures until they are calcined. The remains are then placed into mechanical pulverizers that reduce the remains to ashes. Whether funerary, accidental, or criminal, the analysis of cremated remains (often referred to as **cremains**) can be complex because there are typically few if any bones that retain any morphological features of value. In some cases, elemental analysis to determine the presence of bone may be the furthest extent of possible examinations (e.g., Gilpin, 2013).

FIGURE 13.26 Heat-induced bone fractures

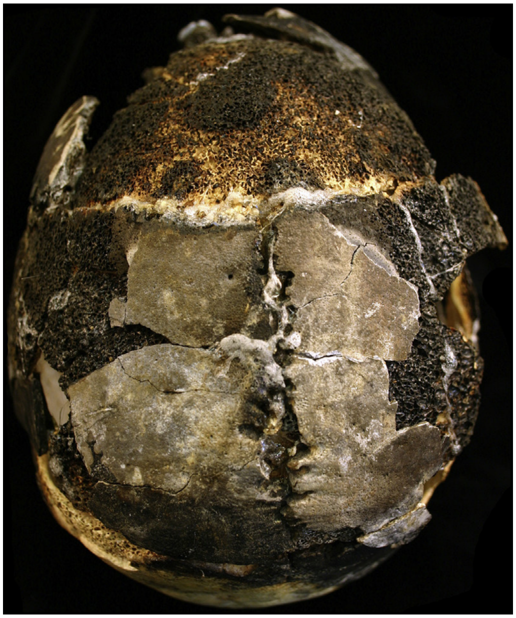


FIGURE 13.27 Delamination in a charred skull

Blast trauma

Blast traumas are complex and are often the product of mixed forces (compression, shearing, and bending) and mixed mechanisms (high velocity projectile, blunt, sharp, and thermal trauma). There is an abundance of literature on blast trauma in the medical and orthopedic fields, but it has been less frequently addressed in the anthropological literature. Most of the medical literature focuses on mortality and treatment of blast

FIGURE 13.28 Commercially cremated remains

injuries, with few controlled studies aimed at investigating patterns of blast injuries, especially those relating to the skeleton. It has received a little more attention in the forensic anthropological literature recently, particularly as it relates to the involvement by anthropologists in humanitarian, conflict-related, and terrorism investigations (Kimmerle and Barabar, 2008; Christensen et al., 2012; Christensen and Smith, 2013).

Blast traumas were first described during World War I, and are categorized as primary, secondary, tertiary, and quaternary. Primary blast traumas are those resulting from barometric changes from the blast wave itself. These tend to affect primarily the hollow organs such as the eardrums, lungs, and bowels, but the blast wave, if strong enough, may also result in injuries affecting the skeleton such as amputation, decapitation, and skeletal fractures. Secondary blast traumas are those resulting from penetrating fragments and shrapnel. These too may affect the skeleton, producing sharp, blunt, or high velocity projectile trauma and associated radiating and concentric fractures. Tertiary blast traumas are the result of large objects falling onto a body, or a body being thrown into objects. Such forces may result in blunt traumas of the skeleton. Quaternary blast traumas include miscellaneous injuries such as burns and smoke inhalation.

Few patterns are recognized in relation to skeletal blast trauma, though blast events have been shown to produce extensively comminuted fractures with numerous small, displaced bone splinters (Christensen et al., 2012). In addition, butterfly fractures of the ribs with the fracture initiation on the visceral rib surface have been noted in association with ventrally-directed blasts and are believed to result from the blast wave expanding the ribcage and bending the ribs outward (Christensen and Smith, 2013) (Figure 13.29).

Fracture patterns from blasts may therefore differ in quality and extent from other types of skeletal trauma such that, if analyzing skeletal remains and the source of the

FIGURE 13.29 Butterfly fractures in ribs resulting from blast events

(From Christensen and Smith, 2013)

trauma in unknown, anthropologists may be able to differentiate between blast trauma and trauma from some other cause. Such a diagnosis, however, requires thorough analysis of the individual skeletal injuries and careful interpretation of the injury distribution over the entire skeleton. Much more research in the area of skeletal blast trauma is needed, especially considering the increasing frequency with which anthropologists are likely to encounter skeletal trauma resulting from explosive events.

13.5 Cause and manner of death

The **cause of death** (or "proximate cause of death") is the medically determined disease or injury responsible for the lethal sequence of events, or the factors that prompt these events to occur. Literally speaking, the cause of death is always the cessation of breathing and the heart beating, but practically speaking, the cause of death is etiologically specific, such as a particular disease, old age, malnutrition, or a gunshot wound. A term often used interchangeably with "cause of death," but which is subtly different, is "mechanism of death" or "immediate cause of death" which is not etiologically specific and refers to the physiological or biochemical alteration whereby the cause exerts its lethal effect (e.g., congestive heart failure, septicemia, etc.). The **manner of death** is a legal distinction for the way someone died, or how the cause of death occurred. While there are countless possibilities for the cause of death, there are only five generally accepted manners of death: homicide, suicide, accident, natural causes, or unknown.

While forensic anthropologists may provide conclusions and opinions regarding skeletal injuries, the determination of the cause and manner of death is the responsibility of the medicolegal authority (e.g., medical examiner or coroner) and not the forensic anthropologist. An anthropologist may discover evidence related to the mechanism of skeletal injury which may or may not have contributed to an individual's death, as well as other observations that may provide evidence pertaining to the manner of death. For example, a forensic anthropologist may conclude that a large caliber projectile entered the right side of the cranium and exited the left side. These conclusions often assist the medicolegal authority in making their determinations of cause and manner of death (i.e., they are the ones responsible for concluding that the previously described wound would have caused death).

Since not all death events leave alterations on the skeleton, however, forensic anthropological examinations may not always provide information relevant to the cause of death. Moreover, even if a mechanism of trauma can be identified by forensic anthropological analysis, it is usually not possible to distinguish based on the trauma pattern alone whether it resulted from, for example, an accident versus intentional violence; such determinations are often dependent on contextual and investigative information.

13.6 Case study – perimortem fall from a height

The University of Tennessee Forensic Anthropology Center (FAC) was contacted regarding a death that had occurred almost 25 years previously, in which decomposed remains of a female were discovered at the bottom of a cliff. The autopsy at the time indicated that no skeletal fractures were present. The family eventually requested another examination due to inconsistencies between the autopsy findings and the death certificate which indicated the cause of death was due to a fall. The remains were exhumed and transported to the FAC for a skeletal trauma analysis.

In contrast with the original autopsy findings, the anthropological analysis revealed extensive perimortem trauma to elements along the midline (Figure 13.30).

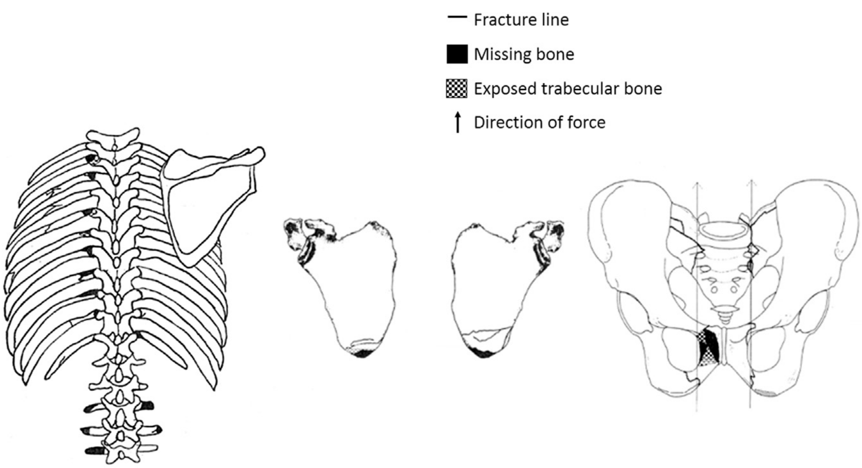


FIGURE 13.30 Trauma from fall from a height

Fractures (complete and incomplete) were found on the ribs, vertebrae, sacrum, teeth, scapulae, and os coxae. The overall pattern of fractures, which included numerous compression fractures of the axial skeleton, was consistent with vertical compression consistent with a fall from a height. The greater number of left-sided fractures further suggested that the individual was probably positioned toward the left side at impact.

13.7 Case study – antemortem and perimortem pediatric trauma

A two-year-old male was visiting his father's residence for six days, during which time the father reported that the child ate well and experienced no accidents or injuries. When the child was returned to his mother's residence, he played, ate, and went to bed. According to the mother, at 4:00am, the mother's boyfriend discovered the child in his room experiencing seizure-like activity. The child was taken to a local hospital but did not recover and was pronounced dead at around 5:30am.

The remains were examined by the Harris County Institute of Forensic Science, where irregularities were noted on several left and right ribs and the right radius and ulna (Figure 13.31). These skeletal elements were removed and processed for an anthropological trauma analysis. Antemortem trauma was noted in the form of fracture healing and subperiosteal new bone formation on six right ribs and three left ribs consistent with constriction of the chest. Additional antemortem trauma was present on the distal right radius and ulna consistent with axial compression. Perimortem

FIGURE 13.31 Antemortem and perimortem blunt trauma on a 2-year-old male

Top: Ribs and right radius and ulna, bottom left: Healing fracture and subperiosteal new bone formation on ribs, center: Healing fracture of the left ulna, and right: Perimortem fracture on rib.

(Images courtesy of Harris County Institute of Forensic Science)

trauma in the form of a torus fracture was noted on a right rib, consistent with anterior directed force to the lower right back. The fractures were concluded to represent a minimum of two traumatic events, one that occurred within three weeks of death and one that occurred very near the time of death. In addition, the autopsy revealed contusions, hemorrhages, and lacerations in various locations throughout the body. The death was determined to result from blunt force injuries.

13.8 Summary

- Skeletal trauma can be characterized by its timing in relation to the death event (antemortem, perimortem, or postmortem alteration) as well as the mechanism that caused the trauma (blunt force, high velocity projectile, sharp force, thermal, or mixed).
- Bones are objects that obey physical laws and understanding bone's response to force can help interpret how fractures may have occurred. The primary forces that cause skeletal fractures are compression, tension, bending, shear, and torsion.
- Fractures may be classified as incomplete or complete, and can be further categorized based on their morphology. Incomplete fractures include bow, greenstick, and depressed fractures. Complete fractures include transverse, oblique, spiral, and comminuted fractures.
- Antemortem trauma is an alteration that occurred prior to the death event, and is primarily evidenced by bone healing. Understanding the sequence and timing of fracture repair can help clarify how long ago the injury occurred, and may reveal trauma pattern histories.
- Perimortem trauma is an alteration that occurred when the bone was in a biomechanically fresh state. This typically includes trauma that occurred very near and is directly related to the death event, but may also include damage that occurred in the postmortem period.
- Postmortem damage refers to alterations to the bone after death and which are unassociated to the death event. These alterations may include taphonomic changes such as scavenging. Certain postmortem alterations may have a relationship to the death event such as dismemberment or thermal alterations.
- Blunt force trauma is caused by the application of relatively low speed force over a relatively large surface area. This may include blows from objects, falls from heights, and transportation accidents.
- Sharp force trauma is caused by the application of force by a tool with a pointed or beveled edge, typically a knife or saw. Sharp force traumas often leave clefts and striations that can be associated to a class of tool.
- High velocity projectile trauma is caused by the application of high-speed force over a small surface area. These injuries may include gunshot as well as shrapnel wounds, and can be recognized by their size, shape, beveling, and fracture pattern.
- Thermal trauma is caused by exposure of the bone to fire or heat resulting in alterations such as color changes, shrinkage, and fractures.

- Blast trauma is an example of a trauma pattern resulting from mixed forces and trauma mechanisms. Contextual information and certain fracture patterns may help identify trauma as resulting from a blast event.
- The results of forensic anthropological assessments of trauma may help the medicolegal authority in determining the cause and manner of death.

13.9 Test yourself

- Explain the relationship between elastic deformation, yield point, plastic deformation, and failure. How do these relate to a bone's strength and toughness?
- What type of directional force do you think might be involved in fractures resulting from a fall? A skiing accident? A collision between a car and a pedestrian? If you have ever fractured a bone, can you identify the directional force that caused it?
- A lawyer in a trial has asked you about an injury that you referred to in your report as a "perimortem fracture." How would you explain to the jury the meaning and significance of this conclusion?
- How would you categorize trauma created by the handle of a knife? Why? What alterations would you expect to see?
- You are presented with a cranium with two roughly circular defects, one on the right side and one on the left. What conclusions might you be able to draw and provide to investigators about these injuries? What would those conclusions be based on?
- Describe how you would go about locating, identifying, and analyzing alterations on remains which are reportedly from the victim of blunt trauma followed by dismemberment.
- You are presented with the contents of an urn which includes several small bone fragments along with a significant amount of ash. What types of analyses might you be able to perform? What conclusions might you be able to make?
- Besides blasts, what other events or scenarios might result in trauma from multiple forces?

Definitions

Alteration A change to the physical properties of skeletal material
Anisotropic Having different mechanical properties in different directions
Antemortem Before death
Ballistic Relating to projectiles and their flight and the internal actions of firearms
Bending A force that applies compression to one side of the bone and tension to the other
Beveling Angling of an alteration resulting from plug-and-spall fractures caused by fast-moving objects
Buttressing The reinforcement of the skeleton (typically in reference to the face or proximal femur) in order to transfer and dissipate forces

Calcined A condition of thermally-altered bone where the organic content and moisture have been lost, usually appearing as a white or gray color
Cause of death The disease or injury responsible for the lethal sequence of events or the factors that prompt these events to occur; also called "proximate cause of death"
Charred A condition of thermally-altered bone where the organic component has been carbonized, usually resulting in a blackened color
Complete fracture A fracture in which there is discontinuity between two or more bone fragments
Compression A force that acts to decrease the bone dimension in the direction of the applied force
Creep fracture Fracture occurring under stress levels less than the failure point due to relatively low static force applied over an extended period of time
Cremains Cremated remains
Cremation The process of thermally reducing remains to calcined bone and/or ash
Delamination Separation of the outer layer of bone of the skull
Dismemberment The act of taking something apart
Dynamic loading Force that is applied suddenly and at relatively high speed
Edentulous The antemortem loss of all teeth, accompanied by the resorption of the alveolar bone
Elastic deformation Temporary deformation in response to a force
Elastic modulus (Young's modulus) A measure of a material's intrinsic ability to resist deformation
Failure Cracking, displacement, or misalignment that results in a material no longer performing as it did previously
Fatigue fracture Fracture occurring under stress levels less than the failure point due to repetitive loading
Fire An exothermic oxidation reaction where fuel is consumed by an oxidizer, generating enough heat to be self sustaining
Force The action of one object on another
Fracture The loss of bone integrity due to mechanical failure
Fracture callus A new mass of bone in the fracture site which bridges the fracture gap
Hangmans's fracture Bilateral fractures of the pedicles of C2
Hematoma A localized collection of blood in the tissues that occurs as a result of broken blood vessels; also called a bruise
Incomplete fracture A fracture in which some continuity is retained between the fractured bone portions
Inflammation A reaction by organisms to injurious stimuli that initiates healing, often characterized by an influx of plasma and white blood cells to the injured area
Isotropic Having the same mechanical properties in all directions
Kerf The notch or groove made by a cutting tool, typically a saw
Load The application of force to an object
Magnitude The amount of force applied
Manner of death The way someone died, or how the cause of death arose; usually homicide, suicide, accidental, natural causes, or unknown
Mechanics The science that deals with the effects of forces on objects
Osteogenic reaction The formation of new bone
Perimortem At or around the time of death; anthropologically, when the bone is in a biomechanically fresh state
Plastic deformation Permanent deformation in response to a force
Postmortem After death

Retort A furnace where remains are cremated
Shear A force involving the sliding of two areas of bone relative to one other, parallel to the direction of force
Spine The thickest section of a knife; in single-bladed knives, this is typically along the opposite edge of the beveled portion of the blade
Static loading Force that is applied slowly
Stiffness The ability of a material to resist deformation when force is applied
Strain The change in dimension (deformation) of a loaded body
Strength A characteristic of a material that is related to the load or stress required to reach the failure point
Stress Load per unit area
Tension A force that acts to increase the dimension of the bone in the direction of the force
Torsion A force involving the combination of shear and twisting
Toughness A measure of the energy absorption capability of a material
Trauma Disruption of living tissue by an outside force
Viscoelastic A characteristic of materials that exhibit both viscous and elastic properties when force is applied, involving a molecular rearrangement when undergoing deformation
Yield point The load point after which material experiences plastic or permanent deformation

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