

An Analysis of Skeletal Trauma Patterning of Accidental and Intentional Injury

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## **Abstract**

The ability to determine the cause of skeletal trauma – i.e. an injury produced by blunt, sharp, or ballistic forces - is critical in assessing the manner of death. The purpose of this study is to examine the patterns of injury between known accidental and intentional trauma cases while considering demographics, fracture features, and the location of injuries in individuals of varying ages, sexes, and ancestries. The current literature has identified a pattern for intentional injuries that is focused on the head, neck, and face, while accidental trauma tends to be more dispersed throughout the skeleton with more injuries found in the limbs.

This study used a macroscopic examination, and fractured bones were assessed by region, completeness, bone class, fracture type, mechanism of injury, and timing of injury. There were individuals of both sexes represented, as well as varying ages and ancestral groups. A total of 227 individuals were incorporated into the study with 857 individual injuries. These data were analyzed using chi-square analyses and logistic regression to discern patterns of injury.

Results indicate that the head was more frequently a target of intentional injuries than expected. Many studies cite the head and neck as the most commonly targeted sites of intentional violence. In contrast, there were more long bone injuries found in accidental trauma. These areas are particularly susceptible to accidental trauma from slips and falls, as well as an individual's attempts to right themselves during such an event. In addition, there was a tendency to see less intentional trauma in older individuals, which may link intentional violence with younger age groups. Lastly, few significant differences existed between ancestral groups, which may show that there is a fairly equal fracture risk for intentional and accidental injuries among the groups studied.

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## **Chapter 1: Introduction**

The ability to determine the cause of skeletal trauma - that is, a skeletal injury produced by blunt, sharp, or ballistic forces - is critical in assessing the manner of death as homicide, accident, suicide, natural, or unknown. The purpose of this study is to examine the patterns of injury between known accidental and intentional trauma cases while considering individual demographics, fracture features, and the location of injuries in individuals of varying ages, sexes, and ancestries. By investigating patterns of trauma in modern US skeletal populations, I will be able to assess the existence of similarities and differences in patterns inherent to different causes of trauma. The research asks, are there distinct patterns inherent to accidental and intentional trauma that allow for differentiation of these injuries in human skeletal remains of people of different known ages, sexes, and ancestries? Does the type of injury (i.e. sharp force, blunt force, or ballistic) lend itself to a certain injury pattern depending on the cause? How might current models of injuries and their locations aid in the interpretation of injury risk and possible causes?

This analysis will take the features of traumatic injury and demographic characteristics into account in an effort to create a guide to the identification of unknown victims, from known human rights violations to those encountered by domestic law enforcement. The significance of identifying the inherent patterns to these causes of trauma cannot be overlooked; as forensic and humanitarian cases involving unknown victims have the potential to accumulate worldwide. If the cause of skeletal trauma cannot be accurately discerned by a forensic anthropologist, then a potential incorrect determination of the liability for death could result. This means that criminal charges could hypothetically be filed against innocent persons, or an intentional trauma could be

misidentified as an accident, or vice versa. Therefore, knowing the patterns that are likely to be exhibited in an accident, such as a fall versus an intentional blow to the head, could potentially prevent a homicide from being ruled an accident.

Current scholarship demonstrates that injuries resulting from accidents tend to be more widely distributed throughout the skeleton, while injuries resulting from intentional causes have a tendency to be more localized (Bhandari et al. 2006; Breiting et al. 1989; Guyomarc'h et al. 2010; Perciaccante et al. 1999; Shepherd et al. 1990; Teh et al. 2003; Walker 2001). However, researchers have not yet adequately addressed if there is a unique, identifiable, and predictable pattern inherent to the injuries that result from different causes (i.e. an accident or intentional injury) or what the statistical significance of these patterns is likely to be (Brink et al. 1998; Crandall et al. 2004; Guyomarc'h et al. 2010; Novak 1998; Petridou et al. 2002). Some studies have shown that there may be considerable overlap among injury locations, meaning that no specific skeletal site is exclusive to a particular cause of injury (Perciaccante et al. 1999). In addition, the degree to which these patterns overlap or resemble each other is not fully understood (Byard et al. 2010; Perciaccante et al. 1999). Therefore, an effort needs to be made to discover potentially unique characteristics of these injury types.

Several patterns of injury locations and types have been proposed for intentional and accidental causes but relevant studies are usually limited in scope as many concentrate on U.S. females, or males, to the exclusion of other demographic categories (Sheridan and Nash 2007). A more comprehensive study is needed to integrate existing findings and test whether they hold up for more than the original study samples. Further complicating the issue is the fact that socio-cultural environments and factors expose individuals to varying risks and types of violence and injury, and may also shape injury patterns. Issues related to structural violence, such as income

disparities, have a profound effect on the health of individuals as access to healthcare and proper nutrition are necessary for the maintenance of good bone health. Differences in these areas can predispose an individual to fractures due to the indirect effects of structural violence. In the same manner, cultural violence can target one portion of the population and combined with the effects of structural violence, can significantly reduce the health of a segment of the population predisposing them to various medical issues (including increased fracture risk) and higher rates of direct violence. The correlations between factors such as age, sex, and ancestry with trauma have been addressed in existing soft tissue research but are not as extensively analyzed in relationship to patterns of skeletal injury (Apel et al. 2011; Lyons et al. 2003; Jonsson et al. 1993; Walker 2001). Therefore, there is a need to further assess how the living social environment and demographic characteristics of deceased individuals are related to patterns of injury. Symbolic and structural violence that targets females and reduces their quality of life may predispose them to injury. In addition, the elderly often manifest skeletal changes, such as osteoporosis, that increase the incidence of fractures in this population. The risk of injury, frequency/type of injury, and socio-cultural and environmental factors need to be further analyzed with respect to fracture features, sex, and age in order to provide a comprehensive picture of accidental and intentional injury patterns.

The risk of traumatic injury varies according to biomechanical constraints (e.g. bone mineral density and turnover rates), as well as the sex, age and exposure to violent conflict of the individual under study. These demographic factors have biomechanical implications for the quality of bone and the likelihood of incurring a fracture caused by an accident or intentional injury. Specific bone features (e.g. bone mineral density) that may change depending on sex and age can contribute to differing patterns in accidental and intentional injuries. Further studies are

needed to assess sex differences, as well as other differences that may be based on ancestry or cultural group, as concerns fracture risk predicated on these biomechanical differences.

In addition, the frequency and type of trauma is often mediated by the biomechanics of the mechanism of injury, defined as “the exchange of physical forces that result in an injury” (Sheridan and Nash 2007: 281). Sheridan and Nash (2007) assessed the trauma environment by identifying the mechanism of injury and found that the most frequently encountered mechanism of injury in domestic assaults is being struck with a hand. Therefore, blunt force trauma has a tendency to dominate these types of injuries. Crandall et al. (2004) had similar findings, but extended their argument to accidents as well as domestic assault. They found that falls and motor vehicle collisions were two primary mechanisms of accidental injuries. In both cases, the face was impacted less frequently, with more injuries seen in the lower and upper extremities. In addition, they found that females who exhibited intentional injuries were younger, on average, than those presenting medically with unintentional injuries. The present study seeks to see if these injury patterns will hold for intentional injury scenarios that extend beyond domestic violence.

Individuals with intentional injuries are often younger than their accidentally injured counterparts (Sheridan and Nash 2007). The research of Petridou et al. (2002) corroborate this claim and found that the majority of domestic assault victims in their study were 39 years of age or younger. In addition, the likelihood that an injury was due to domestic assault decreased sharply after the age of 50. These patterns differed for males within the study and show that males and females may experience different types and degrees of violence. In male victims of domestic assault, the primary targets of the injuries are also the head and face. The age of the majority of victims is older, however. Petridou et al. (2002) found that males who experience

domestic assault tend to be older than their female counterparts, with the majority in the 40-60 year age group. In addition, males' domestic assault injuries tend to be less serious than accidental injuries, which is not true for females. Therefore, a correlation with age will be assessed to support or refute these previous studies.

The risk of incurring an intentional injury will differ depending on whether the individual is in a civilian or military context. Apel et al. (2011) found that in a civilian context, a known attacker is more likely to employ lethal violence than an unknown attacker. In contrast, during wartime, one is trying to impose lethal violence on unknown individuals and there may be less violence directed at acquaintances and kin (Apel et al. 2011). Therefore, the risk of serious intentional injury varies with respect to the socio-cultural and environmental context, which may have variable consequences for males/females and the old/young within a population. The argument could also be made that accidents may be more likely in a wartime environment due to the effects of a close proximity to gunfire and explosives for both civilians and combatants. In order to distinguish accident from intentional injury in such cases, as well as domestic forensic cases, a closer examination of injury type and frequency is warranted.

The frequency and type of trauma examined in the literature concerning civilians is not always applicable to wartime injuries for combatants and non-combatants. Champion et al. (2003) identified the head, chest and abdomen as characteristic locations for penetrating, wartime injuries of combatants, and these injuries are usually sustained by males aged 21-40 years old. Aboutanos and Baker (1997) studied wartime civilian injuries and found that they affect all age groups and sexes with the head incurring the highest mortality rates, followed by the lower and upper extremities. It is possible that the extremity wounds are attempts to defend the body against further injury in these cases, which is paralleled by the literature on interpersonal assaults

(i.e. those not specifically referencing domestic abuse). In a study of autopsy reports of blunt and sharp force homicide, Ambade and Godbole (2006) found that the hand was the most common site of defense injuries. As the head and upper limb were the most frequently injured sites in blunt force trauma, the upper limb prevalence is suggestive of defensive posturing of the victim. The thorax and abdomen, followed by the upper limb, are the most commonly targeted sites in sharp force trauma. This is due to the access afforded to soft, vital organs in the thorax and abdomen and may also reflect the attempt to ward off blows with the upper limb. The same pattern for blunt force injury was found in Brink et al. (1998) and suggests that wounding patterns may be a combination of the initial attack and the attempts of the victim to minimize bodily injury. These injury models have many similarities, but the patterns need to be tested against domestic trauma cases to see if the patterns are similar, or may be specific to the socio-cultural environment and presence of violent conflict.

Environmental and social factors can be significantly intertwined and may predispose an individual to more traumatic injuries from accidents, intentional injuries, or both. An example would be limiting healthcare services to an economically disadvantaged population, which would have the effects of reducing their overall health and bone quality and predisposing them to injury due to their weakened health status. Sex and age differences are also enmeshed in these factors and create different risks and potentials for injury on biomechanical and social grounds. Post-menopausal women are more likely to suffer from osteoporosis, which leaves them more vulnerable to fragility fractures of the proximal femur and distal radius (Sanders et al. 2002). If an individual is also experiencing nutritional stress, this can increase the likelihood of these fractures. Crandall et al. (2012) found that as social stress increases, so does bone turnover (i.e. the remodeling of the microstructure of bone). Bone turnover is an important factor in assessing

bone fragility. Increased rates of turnover are associated with an increase in the risk of fracture, independent of individual age, bone mineral density (BMD), and a history of prior fracture. In males, as economic adversity increases, so do turnover rates. In contrast, females experience higher turnover rates when relegated to a minority race status, which may reflect social constraints on their lives that manifest in their bodies. Sex differences may correlate with differences in biological vulnerability, social coping mechanisms, and access to material and social resources. As such, the biological effects of structural and symbolic violence may be disproportionately affecting females in disadvantaged populations. In addition to these culturally-mediated biological factors, environmental factors, such as area of residence, may also have an effect on individual biomechanics and injury rates. Poor nutrition can also affect biomechanics, as it has an effect on bone structure that generally reduces bone mineral density, thereby reducing the resistance of bone to fracture. Sanders et al. (2002) showed that a low-calcium area had higher fracture rates than a population that had relatively higher calcium rates. Calcium is particularly important to bone health and marginalized populations could experience issues with bone mineral density and bone mineral content (Doblare et al. 2004). Lower BMD levels and higher fracture rates are usually found in an urban environment, compared to rural counterparts (Jonsson et al. 1992; Melton et al. 1999). Sanders et al. (2002) found a 15% lower total fracture rate in rural, compared to urban, samples. These findings may be due to the fact that rural individuals tend to stay active later in life, have lower rates of early retirement, engage in more strenuous physical labor, and are less socially dependent on others for daily activities (Jonsson et al. 1992; Sanders et al. 2002). These studies are compelling, but highlight the need for similar research into individuals of varying ancestries, sexes, and ages to see if the effect is consistent across these categories. In addition, the cause of injury is never identified for these

samples, which could give much needed information regarding whether these injuries are the result of accidental or intentional trauma.

Lastly, this study is largely concerned with direct violence as it is employed between individuals, and accidents that arise unintentionally. It should be noted, however, that there are many other types of trauma that can be ascertained via skeletal analysis. Galtung (1964) characterized violence as a triangle with direct, cultural, and structural violence centered on each point. As they are all interconnected, you can identify one form of violence and trace its affects across the other two forms of violence. Direct violence often takes the form of violence directed at random or selected individuals within a population. This can take place between two individuals, or between governments and whole sections of the population, like in Colombia as an example. This has the potential to amass collections of individuals with large amounts of skeletal trauma. They can be found singly, or in mass graves, where the proper assessment of trauma is necessary to properly identify individuals, as well as to reconstruct the scene in the event criminal charges are filed. In contrast, some forms of violence (such as structural, cultural, or symbolic violence) may be indirectly tied to issues of direct and political violence, as well as fracture risk. As previously noted, access to proper nutrition has a direct effect on bone strength and bone mineral density. If these forms of violence result in an individual or segment of the population with decreased access to food and health services, then fracture rates and injury rates for this disadvantaged population will potentially be higher across all ages, sexes, and ancestries. It is necessary to be aware of all the forms that violence can take when assessing trauma within a sample, as there may be issues that arise from structural violence that increase the susceptibility of an individual to poor bone quality, and subsequently to higher fracture rates.

## **Hypotheses and Aims**

This study will use skeletal data from medical examiner and curated skeletal populations to investigate the potential differences between skeletal trauma caused by accidental and intentional causes, and to determine if these differences correlate with subsets of the population based on age, sex, and ancestry. The following hypotheses will be tested, which address the underlying research questions.

**Hypothesis 1:** There will be a unique injury pattern related to the patterns of accidental trauma that can be assessed in skeletal remains.

This hypothesis will be rejected if a statistically significant correlation is not found between locations, features, and types of injuries and an accidental cause of injury in chi-square analyses. If it is supported, then it is likely that demographics and fracture features play a considerable role in how injury manifests within the skeleton. If hypothesis 1 is not rejected, then injury patterns can form the basis for distinguishing injuries caused by accidents from other injury causes.

**Hypothesis 2:** There is a unique injury pattern related to the patterns of intentional trauma that can be assessed in skeletal remains.

This hypothesis will be rejected if a statistically significant correlation is not found between locations, features, and types of injuries and an intentional cause of injury in chi-square analyses. If it is supported, then it is likely that demographics and fracture features play a considerable role in how injury manifests within the skeleton. If hypothesis 2 is not rejected, then injury patterns

can form the basis for distinguishing injuries caused by a deliberate intent to harm from other injury causes.

**Hypothesis 3:** The patterning found in accidental injuries will be distinguishable from the patterning seen in intentional injuries.

This hypothesis will be rejected if no statistically significant differences exist in chi-square analyses and if logistic regression analyses cannot correctly classify the two groups with accuracy. If there is a small amount of overlap, or no overlap, between the two causes of trauma, then mutually-exclusive patterns can be found and looked for in unknown human cases. This would mean that areas of overlap among intentional and accidental trauma can be identified which will deter investigators from using those criteria in cases of unknown causes of death.

**Hypothesis 4:** There will be distinguishable differences with respect to the way in which trauma was incurred, or the type(s) of fractures among individuals of known ages, sex, or ancestry.

This hypothesis will be rejected if there are no statistically significant correlations between cause and type of injury by age, sex, and/or ancestry based upon chi-square analyses and logistic regression. If, however, differences exist between groups in relation to the cause and type of trauma, then it may be true that different individuals within a population are subject to different societal pressures, such as nutritional deficiencies, income differentials, and exposure to varying levels of violence that may predispose them to more intentional injuries or accidents. If no

differences exist between groups, then these causes of trauma are known to affect individuals randomly and indiscriminately.

## **Chapter 2: Bone biology and mechanics**

Understanding the basics of bone biology is critical in assessing features of fractures, as well as to understanding how external and internal forces can create the changes seen in bone after a traumatic injury. Issues concerning bone strength, loading, and adaptation will reveal that external forces have the ability to differentially affect the expression of trauma in different regions of the body and across differing ages, sexes, and ancestries.

### **Bone Strength**

Bone strength is intimately tied to the vulnerability in incurring a fracture. Bone growth and morphological traits are correlated with fracture risk (Price et al. 2005). In particular, the variation in fracture risk is likely due to genetic variability in bone mineral density (BMD), bone quality, adult bone morphology, and the kinetics of bone loss (Price et al. 2005). Individual genetics determine the rate of growth and the traits of the adult skeleton, so differences in bone strength by age, sex, and ancestry are likely to reflect differences in fracture risk, as well as the areas of the body that may be most susceptible to injury among these groups.

The strength of a bone has a strong correlation with that bone's stiffness and this strength is adapted to the largest repeated and intentional loads (Frost 2003; Turner 2006). Whole bone strength can be understood in reference to four main factors: material properties (i.e. tissue and structural properties), amount of microdamage, the bone mass factor (i.e. the amount and type of bone), and the architectural factor (e.g. shape, size, distribution, cross-sectional area, etc.) (Frost 2003). In particular, subtle changes in a bone's density can lead to larger differences in its

strength and elastic modulus (Hipp and Hayes 2000). As an example, the bones of the skull, which have a higher proportion of cortical bone, do not lose strength with age as is seen in other areas of the body. This is due in part to the relative greater density of cortical bone. The strength of trabecular bone, on the other hand, depends on age of the individual, site of the body, and the loading direction (DeSantis et al. 2007). As strength is also related to density and porosity, increased variability in trabecular bone is not unexpected (Einhorn 1992; Ertas et al. 2011). Variation in bone density is under genetic control. It has been found that in males and females, achieved peak bone density is a strong determinant of osteoporotic fractures. Peak density is achieved at around 18-22 years of age and is under strong genetic control. In fact, 70% of the variability seen in bone density is genetically based. This may be due to the activity of vitamin D receptor (VDR) alleles, though more evidence needs to be collected to determine the strength of the association (Beamer 1996). Additionally, variation in bone strength can be seen across sex and ancestry groups.

Bone mineral density (BMD) has been shown to be greater in males compared to females, and in blacks compared to whites, thereby conferring less fracture risk for denser bones (Wu et al. 2005). Chen et al. (2008) in a study of trabecular (or spongy) bone biomechanics argued that changes in bone volume and trabecular separation were similar for males and females over time, though males had thicker trabeculae and less microdamage with age. In addition, the area of bone resorption increased with age in both males and females. This is noteworthy as increased bone resorption has been associated with an increased risk of fracture and may predispose older populations to fractures from multiple causes. Differences across ancestry group also exist and highlight differential susceptibility to fracture among different groups due to differences in bone strength. Pollack and Laing (2011) found differences in areal BMD and bone mineral content

(BMC) between black and white females in reference to weight-bearing bones, like the tibia. Black females had overall stronger tibiae, likely due to greater estrogen exposure at earlier sexual maturation. This suggests that white females may be more likely to incur fractures in weight-bearing bones, as compared to their black counterparts. Additionally, when looking at the radial bone density of black and white populations, Beamer (1996) found that the black population experienced increased bone mineral density that likely developed during pubertal maturation. In addition, another study found bone mineral content differences between Japanese, Korean, and Taiwanese populations. Therefore, cortical bone is likely the target for strong genetic effects.

Changes in bone architecture, size, and the shape of the mid-diaphyseal region all accumulate with age. Price et al. (2005) found that pre-pubertal bone growth affected adult bone morphology. As measures of adult bone morphology are correlated with the risk of fracture, the changes that bones undergo before puberty will have consequences for bone stability later in life. Changes will accumulate during later adulthood that will affect bone strength in ways that increase fracture rates. The processes of aging can affect the strength of bone, as cortical and trabecular bone will thin with age (Majumdar 2003). Decreasing bone turnover, which occurs with age, has the effect of increasing mineralization and therefore stiffness of bone, leading to increased brittleness. This in turn has consequences for bone strength (Parnell et al. 2012; Turner 2002; Turner 2006). Increased turnover has also been associated with the spontaneous loss of bone mineral density, with bone loss potentially being caused by the increased absorption (Blumsohn 2003; Chen et al. 2008). Increased turnover may also be caused by increased social stress and this could increase the fracture risk (Crandall et al. 2012). Subtle changes in bone density can lead to large differences in the strength of the bone. Trabecular bone is slightly less

strong and stiff than its cortical counterpart for example. Their relative strengths are 0.1 – 1.0 g/cm<sup>3</sup> and 1.8 g/cm<sup>3</sup>, respectively (Hipp and Hayes 2000). For example, the small moment of inertia and cross-sectional area of the tibial diaphysis predisposes it to stress fractures at this site (Hipp and Hayes 2000).

The metaphysis has been shown to be the portion of a long bone that is least adapted to bending, torsion, and shearing. This area is often seen as a point of fracture in individuals with osteoporosis (Frost 2003). This is interesting to note, as the diaphysis of the tibia (especially mid-diaphysis) is stronger than its distal third, owing to the larger cross-sectional area of the mid-diaphysis and the thinner cortex (Schreiber et al. 1998). In addition, the loading of the thigh at midshaft endured greater forces than its distal third (Kerrigan et al. 2004). Decreased bone density at the femoral neck, as well as the diaphysis, frequently occurs during the aging process, which highlights the mechanical changes that can take place during senescence and the importance they have on fracture mechanics in the elderly.

## **Safety Factors**

Bone fractures are often the result of a loading event that exceeds the bone's ability to resist the applied force. The means by which bones can fracture under accidental or repetitive loads can be understood through an examination of safety factors. Safety factors explore the relationship between the load a bone is designed to bear and those encountered in life and may reveal the underlying causes of age-related fractures (Biewener 1993). Daily activities expose an individual's skeleton to a variety of repetitive forces that have the ability to develop microcracks in the loaded bones. As bone is strongest under compressive forces, weaker under tensile forces,

and weakest under shear, it is not surprising that many fractures may occur due to shear failure in accidental or abnormal loading scenarios. As the material properties of bone vary by region, so does the loading environment. The ability of a bone to resist certain loading conditions is dependent on the regional architecture of the skeleton, such as local bone mass, and safety factors can reveal why some areas are more predisposed to fracture as we age (Biewener 1993). It is necessary to understand, however, exactly what a safety factor is and what it is designed to measure.

Safety factors are best expressed as the ratio of load bearing capacity over the load bearing requirement. The inverse can be identified as the factor for the risk of fracture (Biewener 1993; Hipp and Hayes 2000). They represent a tradeoff between metabolic energy costs and time production costs that are roughly linear with mass. There is considerable variation within an individual skeleton, as to the amount of mass that can be biologically attained (Currey 2002). The resistance to fracture is often proportional to mass, and the volume of bone absorbing the load is important in establishing its strength to resist a load. The cost of increasing the mass and therefore the safety factor tends to increase in more highly locomotive individuals/species. As safety factors are determined by the ratio of the cost of building bone to the cost of failure, it is expected that increased strength will require increased mass, and therefore increased cost. The currency of cost, as it relates to the determination of safety factors and bone building, is fitness (Biewener 1993; Currey 2002). Therefore, the loading environment of a bone will determine how much bone is deposited to allow for an adequate safety factor.

Safety factors in the limbs tend to decrease as you move distally, and are overall smaller in relation to the loads imposed during vigorous motion (Currey 2002). Proximal elements tend to have more variation in their robusticity, which may represent an optimization of the

relationship between the need for tissue economy and the need for adequate safety factors (Martin and McCullough 1987; Stock 2006). Distal elements, for example, are under selective pressure to be lightened, thereby reducing the margin of safety (Currey 2002; Shaw and Stock 2009; Stock 2006). As an example, one would expect the tibia to fracture more frequently than the femur, and this is often the case (Currey 2002). In addition, differences in limb lengths can also have an effect on the magnitude of bending moments, which can be integral in understanding fracture risk (Gruss 2007).

For example, the peak loads at the hip joint during a stair climb are about 3-5 times body weight. For a 140 pound person with a 5 times body weight load applied, they should have a femoral load bearing capacity from less than 1 to five times as strong as needed. The exact figures will depend on the individual properties of the femur. The tibia has walking axial loads of 3-6 times body weight and the greatest bending load is 79 Newton-meters (N-m) in males. The tibia failed in three-point bending loads at 57.9 – 294 N-m. The bending strength of the tibia is thereby 1-4 times the maximum applied bending loads (Hipp and Hayes 2000). Muscle contractions can cause appreciable loads to be applied to the femoral head. Hip fractures at this site could therefore be the cause of a fall. The average fracture force of such injuries is 4.5 times body weight. During walking, the iliopsoas muscle can exert forces up to 4 times body weight, and gluteus medius can exert forces up to 3 times body weight, thereby indicating that either muscle can produce fracture forces necessary for injury, especially in the aged (Yang et al. 1996).

In general, bones should fail predominately by accident, or due to fatigue, though this is often not the case (Currey 2002). It is true that safety fractures prove insufficient in preventing fractures from time to time. If a bone has a small safety factor, it can be concluded that the

forces they undergo are fairly predictable. In healthy young adults, load bearing bones should have around six times more strength than necessary to withstand the largest repeated and intentional loads above the threshold for fracture (Frost 2003). In general, safety factors should not be less than 3.4, otherwise fatigue would increase fracture rates. The remodeling of fatigue-damaged bone allows for the reduction of fatigue fractures, and can accommodate the existence of smaller safety factors. Safety factors in the human skeleton vary from 0-5.6. Strains have been measured during locomotion, as well as the strength of bone in comparison to with the stresses encountered during extreme activity. These studies have shown that there is a close relationship between encountered loads and the strength of bone, which can reveal the adaptations made for locomotion. The maximum stresses encountered should scale proportionally with mass and size. This means that in order to ensure less fractures, one must change their habits, or undergo some variety of a shape change. Bone, as a material, responds adaptively to dynamic strains (Currey 2002).

Strain is an important concept in the determination of safety factors. Biewener (1993) has determined that peak functional strains are measured at about -1500 to -2500 microstrain (strain  $\times 10^{-6}$ ). The strain to fracture is about -25000 microstrain, which accounts for an adequate safety factor for many bones. Strenuous activity, however, can produce strains in excess of the upper limit of these peak functional strains. The yield strain of -7000 microstrain is often overlooked and may be more important for assessing fracture risk, as it reflects deformation to the point that is unrecoverable. This is especially important for assessing fractures in the elderly, as the loss of bone due to age-related changes, such as bone loss from osteoporosis, will decrease the safety factor and increase the risk of fracture (Biewener 1993). Overall, the combination of

bone loss and the accumulation of fatigue damage will work to increase the susceptibility to accidental fracture in older individuals.

Safety factors are not always able to prevent breaks in bones, especially as the material properties change with age. Cortical bone tends to thin with advancing age and trabecular bone will experience increased spacing and loss of horizontal trabeculae, which has mechanical consequences (Currey 2008; Kakar and Einhorn 2008; Hipp and Hayes 2000). Yang et al. (1995) has shown that hip fractures can be caused by osteoporosis paired with spontaneous muscle contractions. The cortical bone of the proximal femur thins considerably with age, especially compared with other areas of the femur predisposing it to increased fractures. The average force of a hip fracture is 4.5 times body weight. During walking, the iliopsoas muscle has an average maximum force of 4 times body weight and the gluteus medius muscle is 3 times body weight. As bone ages, either muscle could exceed the safety factor of the proximal femur and cause a fracture. Therefore, the falls that are commonly identified as the cause of some hip fractures may actually be the result of a fracture prior to the fall (Yang et al. 1995).

## **Bone Loading**

The mechanical stimulus that is applied to bone during variable loading events has the ability to change the morphology and stability of the bone matrix. In particular, the cross-sectional area of the bone may undergo loading-related shape changes that have potential costs to the bone's ability to resist the loaded forces (Robling and Turner 2009; Shaw and Stock 2009). This will have significant consequences for fracture risk, as the ability to respond to these

external stimuli will change depending on age of the individual and the region of the body that is loaded.

Bone detects loading from its environment via the network of osteocytes that are buried within the bone matrix. These are the proposed mechanoreceptors and they can detect changes in strain due to a variety of mechanical forces (Burr et al. 2002; Lanyon 1993; Robling and Turner 2009; Ruimerman and Huiskes 2005). The osteocytes are essentially bathed in extracellular fluid that moves in response to dynamic loading events. The movement of the fluid around the osteocyte produces the required stimulus to initiate an osteogenic effect (Burr et al. 2002; Robling and Turner 2009). The osteocytes themselves are linked via canaliculi and can transmit signals via the gap junction when strains are detected. Lanyon (1993) suggests that osteocytes and surface osteoblasts (which cover the outside portion of the bone) are in communication and detect strains, especially those above a certain threshold, which can trigger a modeling/remodeling response. The exact threshold is not specifically known for all bones, but it is purported to be something beyond the regular, intentional loads imposed on the bone. Once a significant strain is detected these cells release prostacyclin which initiates bone depositional activity. Bone is deposited in areas of strain in an effort to bring forces back to a more “optimal” level (Burr et al. 2002; Lanyon 1993; Robling and Turner 2009; Ruimerman and Huiskes 2005).

The mechanical effects of loading on the microscopic morphology of bone chiefly concern the resorption and deposition of bone according to functional requirements. Once strain has reached a significant threshold, it will require the deposition of new bone in order to ameliorate the effects of the strain. As an example, if we consider a bending force, then bone deposited in a way that increases the distance from the neutral axis will confer more bending rigidity, which will help resist bending strain (Currey 2002). In cortical bone, this will involve

deposition or resorption on the endosteal and/or periosteal surface. Changes to the cross-sectional geometry will occur when strain is high in order to bring it back to a more optimal strain level (Ruimerman and Huiskes 2005). If an individual experiences decreased mobility (e.g. through paralysis) the bone will also be resorbed from the endosteal surface. This is seen in the elderly as resorption at the endosteal surface does function to confer more bending rigidity, however, the increased frailty of the bone still leaves it susceptible to fracture (Hipp and Hayes 2000). This pattern of deposition and resorption is slightly different in subadults. This is because most deposition will occur subperiosteally rather than endosteally, as in adults. In trabecular bone, trabeculae orientation will also be influenced by strains and the trabeculae will orient themselves in the configuration that best resists the applied forces (Robling and Turner 2009; Ruimerman and Huiskes 2005). The loading environment will continue to shape bone as microcracks will develop and stimulate remodeling in response to applied loads.

Robling and Turner (2009) found that mechanical loading not only adds bone to the areas experiencing greater strain, but it also reshapes the cross-sectional morphology into a more efficient form. Exercise has the effect of reducing bone turnover by decreasing resorption, which will preserve a more optimal bone mass. Bone cells are responsive to mechanical stimuli in the “short term.” This means that repeated, continuous stimuli will have a decreasing osteogenic effect over time, referred to as “diminishing returns.” This can be explained as mechanosensory saturation to the applied stimulus. If a recovery period between loading sessions last about four to eight hours, then the bone cells can regain their mechanosensitivity. In addition, a short break between individual loading cycles, even just a few seconds, can also enhance the osteogenic effect of the loading session. The recovery period is necessary to achieve the greatest osteogenic gains from the applied stimulus (Robling and Turner 2009).

Overuse in loading causes small microcracks to develop that spur bone remodeling in the areas experiencing the strain (Robling and Turner 2009). In general, two types of discontinuity are seen: diffuse damage that is likely to be damage at the level of the collagen fibril, and linear microcracks. These two types of discontinuity in the bone matrix are potentially due to different mechanical stresses, as diffuse damage is usually seen in tensile cortices, whereas microcracks are usually seen in compressive cortices. The repair mechanisms for these two types are also different as diffuse damage is likely to heal by direct mineral deposition (annealing), or by ionic bond bridging in the organic matrix (sacrificial bonds). In contrast, microcracks are often healed by remodeling, though these healing processes need not be mutually exclusive (Burr 2014).

If strain increases to the point where a microcrack will propagate in the matrix, then complex processes begin to initiate. Most microcracks will be deflected into the cement line (sheath) surrounding the osteon. This is an area of less mineralization that promotes the deflection of cracks by providing a less stiff interface for the crack to propagate. Once it has hit the cement line, it functions to blunt the crack tip. In order to continue to grow in length, more surface energy is now required at the crack tip, because the surface area has increased requiring more surface energy to continue. Therefore, crack propagation will require significantly more force than if it had not been deflected by the cement line. If enough energy is then applied, it will cause a crack that disrupts the structure of the osteon (Kakar and Einhorn 2008; Mishinski and Ural 2011). The crack is usually detected when it disrupts cellular processes, such as nutrient flow, and causes debonding of the osteon. This will then initiate a basic multicellular unit (BMU) that will dispatch multi-nucleated osteoclasts that will start to resorb the bone in the area of the crack. These osteoclasts can cut through more than 40  $\mu\text{m}$  of bone per day. They are trailed by osteoblasts that deposit new bone at a slower rate of about 1  $\mu\text{m}$  per day. The entire

process usually takes about 3-6 months. Cortical bone and trabecular bone have similar mechanisms for repair of this nature. In trabecular bone, however, hemi-osteons can sometimes be formed as the bone material is more porous, which is not seen in cortical bone. Crack resistance tends to be better in planes perpendicular to the osteons, as cracks that initiate in the osteonal plane have a higher incidence of disrupting cellular processes (Currey 2003; Hipp and Hayes 2000; Mischinski and Ural 2011).

As an individual ages, loading events have the ability to produce fracture at an increased rate compared to a young individual. This is due to several factors that affect and control the response of bone to loading. First, Burr (2014) found that younger individuals tend to have more diffuse damage than older individuals. This is important for fracture risk, as diffuse damage dissipates more energy and increases the fatigue life of the bone matrix. Older individuals, who display more microcracks, often experience a reduced fatigue life, as a result. It is likely that the ability of the bone to exhibit diffuse damage decreases with age. Therefore, the ratio of diffuse damage to microcracking may be a predictor for bone fragility, and also fracture risk.

Additionally, older individuals tend to have more brittle bones and experience more cracks that pass through an osteon, which are more detrimental as a crack through one osteon is likely to encourage another. Crack spread is also more easily accomplished in a large crack (for example, one larger than the 200 um diameter of an osteon) compared to a small crack, because it requires relatively less surface energy to propagate. In contrast, younger individuals have more cracks that are stopped by the cement line, which is more effective at stopping crack growth. The decreased turnover rates of elderly individuals also ensure that there is a higher number of older (i.e. more brittle osteons) which can help spread a crack. In younger individuals, newer osteons formed via remodeling will deflect cracks away from older, more brittle osteons, providing more

of a deterrent to crack propagation. This ability is reduced in the elderly, which increases susceptibility to fractures from loading events within the normal range (Currey 2003; Hipp and Hayes 2000; Mischinski and Ural 2011).

For example, a long bone (e.g. the femur) experiences several different types of loading that include compression, shear, torsion, bending, and tension, which have effects on its morphology. The forces of compression come from the weight-bearing role of the femur and are responsible for variation in the deposition of bone around the diaphysis. Diaphyseal differences have been addressed by Ruff (2006) who noted that diaphyseal dimensions are more correlated with current body weight and the femoral head is more closely linked to body weight at age eighteen. Therefore, the current weight-bearing role (i.e. compressive forces) is reflected in the diaphyseal dimensions. The shear forces experienced by the long bones are usually related to compression and long bones chiefly fail in compression along oblique shear lines (Currey 2002).

In addition, the femur also experiences bending and torsional loads related to its weight-bearing and locomotor functions. Kerrigan et al. (2004) have shown that the femoral diaphysis is likely to experience a degree of torsion and bending, as the shape is circular. This shape has been shown to be particularly effective in resisting torsional loads and also helps with loads applied in different directions. This is particularly important for a long bone, such as the femur, which has a high degree of mobility during the gait cycle. The forces associated with tension are mostly experienced via bending, a combination of forces that generates tension on one side and compression on the other. The shape of some of the long bones of the lower limb, for example the tibia, promotes anterior tension and posterior compression in bending during locomotion. As bone is weaker in tension than compression, this leads to fractures on the tension side. This is evidenced by the fact that many fatigue fractures of the tibia occur on the anterior surface, where

tensile forces will be the greatest during prolonged, repetitive loadings, such as jogging (Kakar and Einhorn 2008; Mischinski and Ural 2008).

In addition, a non-weight-bearing bone, such as the bones of the upper limb can also experience torsional forces that lead to differences in bone morphology. Shaw and Stock (2009) looked at the bones of the arm in cricket players and noted that asymmetries existed between the arms. The dominant arm tended to have more dense bones, as well as a more circular humerus, which is evidence of increase torsional loads. This shows a clear difference due to differential mechanical loading. Similar patterns are rarely seen in the lower limb, as they are more constrained by their locomotor function and any asymmetries could be costly with respect to an individual's fitness (Ruff 1984).

Lastly, bone has the ability to detect loads on the cellular level and transform the material and structural properties to reflect the loading imposed upon it. The mechanisms that operate on cortical and trabecular bone are similar, but have key differences that reflect the material properties of each type of skeletal tissue. Current biomechanical studies are helping to illustrate how certain types of loading can affect the morphology of our skeleton. Lastly, the macroscopic skeletal form is the ultimate by-product of these processes that allows our skeleton to function under various loads.

## **Location and loading environment**

The response of bone to loading varies not only by the bone, but by the specific area within the element. The response of the whole bone, as well as its constituent segments, varies due to the underlying structure of the bone. The reasons why such differences exist is linked to

the material properties of the bone, climate effects, and the maintenance of safety factors among other reasons. These differences are important to understanding how bone will react under various loading conditions, as well as how it can possibly fail under such loading.

First, the diaphysis will be discussed in relation to the loading environment. The diaphyses of long bones are composed primarily of cortical bone, which is much denser and stiffer than trabecular bone (average 1.8 g/cm<sup>3</sup> vs. 0.1-1.0 g/cm<sup>3</sup>, respectively) (Hipp and Hayes 2000). This lends an advantage in resisting compressive forces, but also allows for less post-yield deformation and reduced resistance to crack formation (Currey 2002). This is of special importance in the lower limb, where there is a weight-bearing and locomotor function for the skeletal elements in this area. Schreiber et al. (1998) studied the effects of loading conditions on the tibia at the diaphysis and distal third. They found that the tibial diaphysis was better able to resist compressive and torsional load, compared to the distal third of the segment. This is due to the fact that the tibial diaphysis has a larger cross-sectional area and a thicker cortical layer than the distal third, which confers an advantage when resisting compressive, bending, and torsional loads. The larger cross-sectional area moves the outer edge of the bone further away from its neutral axis; this increases the second moment of area and provides increased stability during bending. The effect is the same as looking at a yard stick and seeing that the edge that is thinner (i.e. closer to the neutral axis) is more easily bent, whereas the edge further from the center cannot be bent as easily (Hipp and Hayes 2000). In addition, De Santis et al. (2007) noted that the medial portion of the proximal tibia was stronger than the lateral, which may be a reflection of forces transmitted during movement, which contribute to regional differences, and provide support for functional adaptations to gait.

The femur also experiences similar forces, though loading of this area can be different than the tibia. Kerrigan et al. (2004) looked at loading conditions of the femoral diaphysis and its distal third. They found that the femur is much more resistant to a variety of forces at the diaphysis, as compared to its distal portion. This is due to the fact that the femoral diaphysis is circular and this is the best shape to deflect forces coming from a variety of directions. In contrast, the tibial diaphysis has a more triangular shape, which can affect how it is loaded-creating for bending moments with vigorous activity. Rabl (1996) found that the flatter posterior surface of the tibial diaphysis predisposed it to more direct fractures, as there was less of a propensity to deflect blows (compared to an area like the femoral diaphysis) owing to the flatter surface. Trinkaus (2000) noted, however, that both areas need an adequate amount of exercise to maintain their cross-sectional area, and that static or low-intensity loads can lead to resorption along the diaphysis. Therefore, though there are differences by section and between elements, there are some loading similarities in the diaphysis of both long bones.

In contrast, the epiphyses of long bones contain much more trabecular bone, which changes the response to mechanical loading. Trabecular bone is overall less dense, as previously discussed, which makes it less stiff than cortical bone, but also confers more toughness. This allows for more post-yield deformation, as compared to an area that is more densely populated with cortical bone (Currey 2002; Hipp and Hayes 2000). Ruff (1993, 2000) found that joints and articulations respond more weakly to loading than diaphyses. In fact, they found that in the femur, the femoral head experiences little to no change with increased body weight whereas the diaphysis cross-section remodels more actively under increased loading and is a more accurate reflection of current body weight. In other words, heavier individuals tend to have smaller femoral heads compared to their diaphyses, and lighter individuals tend to have larger femoral

heads as compared to their diaphyses. This is evidence that articulation sites are less developmentally plastic than the diaphyses, which may experience significantly larger levels of deposition/resorption due to mechanical loading (Ruff 1993, 2006). The metaphysis also experiences different loading responses, as it is the part of the element that is least adapted to shearing, torsion, and bending. This is a contributing factor to the high rates of metaphysis fractures seen in individuals with osteoporosis (Frost 2003). As the cortical bone thins with age, and the trabecular bone loses increasing numbers of horizontal trabeculae and experiences increased trabecular spacing, this area becomes a weak point in loading, which can predispose it to fractures over other areas (Frost 2003).

A combination of trabecular bone loading and cortical bone loading was addressed by Shaw and Ryan (2012) with respect to locomotor patterns in eight anthropoid species. They found that the diaphyseal cortical bone was more reflective of locomotor patterns than trabecular bone of the humerus and femur. In addition, the femoral head was much more substantial than the humeral head in terms of trabeculae number and thickness, owing to the weight-bearing demands of the femur. They proposed that the humerus can be modelled as a single beam, whereas the femur is best modelled as two beams, one at diaphysis and one at the neck. This highlights the fact that a multitude of factors affect a bone's response to loading.

Length dimensions in bone are also important in assessing responses to loading, as the bending moment of a long bone is proportional to bone length (Currey 2002). Differences in length, therefore, can contribute to differing levels of stability during loading. Gruss et al. (2007) have shown that the manipulation of bending moments during gait can contribute to increased stability in elements that experience increased loading. For example, the authors looked at slipping and how manipulation of the limb can affect the bending moment. During

slips, if the center of pressure is moved forward, along with an increased flexion moment at the knee, then this will result in a shorter moment arm with mitigated ground reaction forces that helps to decrease the bending moment. This can help protect areas of the element (e.g. the tibial distal third) that are more susceptible to bending forces through postural adjustments.

Redfern et al. (2001) noted similar postural adjustments in slips, especially among the elderly. In order to increase stability, step lengths were decreased which provided a more stable base of support. The question was then raised why the elderly still experience such high fractures, despite the postural adjustments. This was due to the increased porosity and fragility of the bone paired with a more rapid heel strike. Since the heel was placed on the ground with more force and at a more rapid rate, which could be the effect of trying to reduce the swing phase of the gait cycle, the required coefficient of friction was not reduced. Slips remained similarly likely and affected the distal elements preferentially, as they tend to have increased frailty due to smaller cross-sectional areas compared to proximal elements (Kerrigan et al. 2004; Schreiber et al. 1998).

In addition, Ruff (1984) noted that an increase in bone length was correlated with an increase in sub-periosteal breadth. This is most likely an effort to maintain a functional safety factor within the element. The maintenance of safety factors may be a reason for different areas of bone displaying different loading responses. Currey (2002) has shown that safety factors tend to decrease as one moves from proximal to distal in a limb and this is due to the fact that the more mobile distal segments have more tissue economy due to their location and function (Shaw and Stock 2009). In fact, if the lower limb is taken as an example, you will find that during stair climbing, the femur maintains a safety factor of 1-5 times body weight during weight acceptance, depending on the material properties of the individual. In the tibia, the bending force

has a safety factor of 1-4 times body weight and a safety factor of 1-3 times body weight in torsion (Hipp and Hayes 2008). Currey (2002) states that a safety factor of less than 3.4 times body weight has the potential to make fatigue fractures likely, so there must be some mitigating mechanism for distal elements. As the distal elements are selected for tissue economy, the increased mass needed to increase bone strength may have too high a metabolic cost for production and maintenance compared to the cost of failure. It turns out that if microdamage can be remodeled, then the safety factor can be reduced without a detriment to fitness (Currey 2002).

In closing, bone does respond in different ways along the length of the element. There are similarities as well; however, the differences help to determine how loading can affect the unique shape of each portion of a bone. In addition, understanding the loading responses is important for understanding how these forces can be mitigated through behavior, as well as aid in the understanding of why they sometimes encourage/prevent a fracture.

## **Bone adaptation**

Bone functional adaptation proposed by Ruff et al. (2006) proposes that bones exist in a mechanical environment to which they can adapt throughout their lifetime. The applied loads are sensed by the bones and modeling/remodeling activities will take place in response. This is an improvement in Wolff's law as it can be evidenced in the modern biomechanical literature and has empirical support. In addition, it has been confined to biomechanical analyses of diaphyseal cross-sectional geometry, for which it is a suitable application. In short, this models dynamic processes that are affected by many factors including age and activity level, which will be used to outline its validity (Ruff et al. 2006).

Diaphyseal shape and size variations seen in long bones occurs during ontogeny and are mediated by mechanical, nutritional, hormonal, and genetic patterning. The femur and tibia have been the subject of studies on diaphyseal change and have shown that there are clear distinctions in the adaptation of bone to stress during growth. In particular, the distal femur shows a tendency to go from more asymmetric to more circular morphology during development. This is likely due to cortical bone expansion along the anterior-posterior plane, which can be attributed as the response to the bending forces of the knee during walking and running (Gosman et al. 2013). In contrast, the proximal half of the tibia, undergoes a change from a more circular to a more triangular morphology. This change is likely due to growth in the anterior-posterior axis. Two periods of significant change were identified that corresponded to early childhood and pubertal changes. A significant change occurred between the 0-1.9 year age group and the 2-4.9 years age group, which corresponds to a time in life when locomotor skills are developing. The second period of significant change occurred between the 9-13.9 years age group and the 14-17.9 years age group. This is likely reflective of pre-pubertal hormonal and body mass increases, which increase periosteal expansion and endosteal reshaping (Gosman et al. 2013). This patterning is important, as it sets the foundation for adaptation in later years.

Ruff et al. (2006) showed that there are functionally adaptive differences in adults and subadults. Modeling activities in subadults tend to proceed at a much faster rate and involve deposition of bone in response to applied strains in semi-predictable patterns (i.e. semi-predictable as the activity level and other physiological factors are not always known). For example, in younger individuals, bone deposition tends to occur on the sub-periosteal surface. This is very efficient, as a small deposition of bone in this area increases strength considerably and thereby reduces the effect of the applied forces and returning the bone to a more optimal

state. In contrast, adult deposition of bone proceeds at a much slower rate and usually occurs on the endosteal surface. This is the surface where both adult deposition and resorption take place. This is not as efficient as sub-periosteal deposition, because a thicker layer of bone is needed to achieve the same increase in strength. Therefore, adults do still experience functional adaptation, the opposite of which has been argued by some (e.g. Lieberman), albeit at a much slower rate (Ruff et al. 2006).

The activity level of the individual also affects bone functional adaptation as more vigorous activity results in higher applied loads. Shaw and Stock (2009) provide evidence for this as they looked at asymmetry in the upper limb of both swimmers and cricket players. Swimmers tended to use both arms, more or less equally, in the performance of swimming tasks. As a result, both limbs were relatively symmetric with respect to diaphyseal cross-sectional geometry. In contrast, the cricket players, especially those engaged in overhead throwing, displayed bilateral asymmetry. The arm that was employed in the execution of more vigorous athletic tasks (for example, throwing) experienced changes in diaphyseal morphology. In particular, torsional forces associated with the throwing motion directed changes in the cross-sectional geometry that favored a shape that better resisted these forces. The humeral diaphysis took on a more circular shape, which provided more resistance to torsional strain and would result in less injury during the performance of throwing tasks. Ruff et al. (2006) also noted similar changes in subadults engaged in throwing activities. It's important to note, however, that even adults who took up sporting events later in life (some starting at 34 years) still experienced changes in bone morphology. These did not progress at the rate of subadult functional adaptation, but they do represent a response on the part of the bone to its mechanical environment.

The bone functional adaptation model also allows for predictions to be made about the lifestyles of skeletal remains, both fossil and more modern. For example, if we know that increased forces due to more vigorous locomotion are likely to change the shape of the tibial diaphysis in response to loading, then we can look at past populations to see if these changes are evidenced in the skeletal material. If vigorous running is a component of the lifestyle, then one might imagine that more anterior-posterior deposition might take place, as this corresponds to the planes of bending forces in the lower limb, though medial-lateral deposition does occur as well. In addition, if we see a more circular humeral diaphysis, we can expect that the individual engaged in activities that created significant torsional loads on the upper arm. Thereby, the model will allow for some inferences to be made about the mechanical environment of the bones in question (Ruff et al. 2006).

Despite the advantages of the current model, there are some drawbacks. First, long-term studies of how adult bones adapt are needed. This is a point acknowledged by the authors (Ruff et al. 2006), as they concede that adult adaptation proceeds at a much slower rate and requires studies with significant time depth in order to monitor fully. Relatedly, the effect of osteoporosis should be assessed in relation to the model. In post-menopausal women, bone density decreases by 15%, which has consequences for fracture resistance and most likely has consequences for how bones adapt to loads as well (Currey 2002). Several studies have shown that turnover decreases as individuals age. This increases the number of old osteons, which are more brittle and less effective at deflecting cracks. If turnover decreases, then it seems likely that the ability to respond to applied strains is thereby directly affected (Browner and Green 2008).

Second, differences in physiological factors have not been considered by the model. These would include differences due to hormones, diet, and other lifestyle factors. Again, post-

menopausal women may experience differences in functional adaptation due to the decrease in estrogen levels around menopause. In younger individuals, estrogen helps to promote epiphyseal closure and in adults it helps to regulate remodeling activity, which would have a direct effect on the capacity to respond to the mechanical environment. Diet may also affect the rate and ability of bone to respond to the mechanical environment and it is not addressed in the model proposed here. Sogaard et al. (2007) when analyzing calcium intake and how it affected fracture rates, noted that the calcium deficient population sustained more fractures than the calcium-rich sample. Dietary differences of this nature may potentially have an affected on bone's ability to adapt to the mechanical environment, but further studies will have to be done. In addition, Bernstein et al (2010) have shown that circulating levels of growth hormone/insulin-like growth factor (GH/IGF) can affect remodeling activity. If differences in circulating GH/IGF levels, or tissue responsiveness to the hormones, exist in the population, then this will have an effect on an individual's ability to respond to mechanical loads placed on their bone.

In conclusion, the bone functional adaptation model holds significant promise for future studies that concern how bone adapts to the mechanical environment. There is ample support that subadults and adults do experience adaptation based on lifetime loads. Further studies are needed as concerns the capacity for adaptation in adult bones, as well as physiological factors that may affect the model. In short, Ruff et al. (2006) have proposed a valid reconfiguration of the general sense of Wolff's law that promises to further our understanding of how bones change based on mechanical loads.

## **Chapter 3: Trauma mechanisms, fracturing, and demographics**

The following chapter will introduce the basic terms and concepts used in trauma studies. They will reflect the timing and mechanism of injuries, as well as fracture types and patterns of injury.

### **Timing of Injuries**

#### **The Meaning of Perimortem**

The term “perimortem” has had a contentious history within the field of forensic anthropology due to the variability and vagueness in its application. Sauer (1998) originally uses the term to refer to “at or around the time of death”, but this application was then contested, because some fracture features that were considered perimortem could continue into the postmortem interval. For example, Ubelaker and Adams (1995) found that butterfly fractures, which were once considered a perimortem phenomenon, could be produced postmortem and did not necessarily relate to the time of death. Therefore, the term perimortem required more clarity and subsequent retooling.

Wieberg and Wescott (2008) further identified the need to re-evaluate the term when they showed that bones retain their moisture content well after death and that moisture levels decrease for about two months after the individual has passed. In fact, elements with a PMI (postmortem interval) of 57-113 days showed evidence of both dry and fresh fracture characteristics. This complicates the use of a term like perimortem, where the tendency would be to infer that such injuries would then have legal significance, if they were at or around the time of death. Wieberg and Wescott (2008) suggested using the terms fresh and dry to reflect the state of the bone, rather than a temporally-defined period that has a specific legal weight. Wheatley (2008) also

advocated the use of fresh vs. dry characteristics, as perimortem carries too many underlying implications. Recently, the Scientific Working Group- Anthropology (SWGANTH), has established trauma analysis guidelines that advocate the use of ante- and perimortem for trauma and postmortem breakage is considered part of taphonomy and need not be addressed in the same section as a trauma analysis. They base these classifications off of fresh fracture patterning and healing that would indicate peri- and antemortem injuries, respectively.

The timing of injury is very important to a trauma analysis, equal to discovering the mechanism of injury. Villa and Mahieu (1991) established some guidelines for determining what would be considered appropriate criteria for identifying each category. Antemortem injuries are identified by an osteogenic reaction. This is any attempt the body makes to heal prior to death and covers a broad range of reactions, including resorption of necrotic tissue to the formation of a fracture callus and its eventual remodeling (McKinley 2003). Perimortem injury was characterized by fracture outlines that were v- or u-shaped, fracture angles that were obtuse or acute, fracture edges that were smooth, but had sharpness to them, and evidence of peeling or flaking akin to “greenstick” fractures. Postmortem damage was identified by differences in color between the fracture edge and the rest of the bone, fracture outlines that were more transverse, fracture angles that were right angles, and fracture edges that were jagged with a blunting of the ends (Villa and Mahieu 1991). Pechnikova et al. (2011) looked microscopically to see if how the osteons break could be an indication of perimortem trauma or post-mortem alteration. The study found that in both peri-and postmortem events, fractures are twice as likely to travel through the osteon, rather than the cement lines, and did not provide a basis for discerning one (perimortem) from the other (postmortem) based on osteon fracture patterns. Therefore, the choice of

characteristics used to determine perimortem trauma should be well-tested and based on sound and reliable research (SWANGTH 2015).

A more in-depth discussion of healing can further illuminate how ante- and perimortem injuries can be identified. Within the first 24 hours after a fracture, a hematoma forms, which functions to hydraulically stabilize the injury and pain encourages the individual to keep the limb immobilized. Osteoclasts and osteoblasts proliferate at the injury site and initiate the inflammation response. One of the first tell-tale signs of an osteogenic response is increased porosity at the fracture ends. This is the result of osteoclasts resorbing bone back to viable, vascularized segments. On either end of the fracture site, osteoblasts will begin to directly deposit woven bone by means of intramembranous ossification (Doblare et al. 2004; McKinley 2003).

At the same time, the center of the callus remains granulation tissue as there are still high strains, when the callus is more stable, chondrocytes will invade and proliferate creating cartilage in the fibrin-mesh network already established by fibroblasts. Once strain levels are <10 % cartilage will form, mature, and then degrade. Blood vessels will then invade and reconstitute the blood supply (apoptosis) and once the strain is <1% osteogenesis will commence. Woven bone will be laid down; it's identified by the random orientation of its fibers. The callus will continue to form until the fracture ends reach pre-fracture stability (3-6 months). The process of remodeling then takes place (where the woven bone is replaced with lamellar bone) and can continue for up to 7 years (Doblare et al. 2004; McKinley 2003; Schell et al. 2006; Wraighte and Scammell 2006). The presence of the early resorption and the hard callus should mark the injury as ante-mortem. If only the early resorption is evidenced, then a researcher can identify this

injury as occurring close to the time of death, though a definitive time cannot be given as healing is an individual response depending on age, fracture site, health, and activity level.

In like manner, a more in-depth discussion of postmortem damage can reveal how these events are unlike the previously discussed trauma. Quatrehomme and Iscan (1997) identified that features of the external environment, such as sunlight, soil moisture, and animal activity, which can influence the appearance of skeletal remains before discovery. Calce and Rogers (2007) noted that freeze-thaw cycles, rain, snow, and soil can damage a bone to the point that blunt force trauma is no longer visible. Weathering can produce longitudinal cracks in the bone that parallel osteon orientation, and differ from the oblique or transverse fractures seen in some trauma cases. In addition, plants can grow into the bones separating the elements and mimicking trauma. Roots can also secrete certain acids that etch the bone and may mimic cut marks or other sharp force trauma (Quatrehomme and Iscan 1997; Calce and Rogers 2007). It's important to remember that dry bone is much more brittle than its fresh counterpart (due to lack of moisture and organic matrix) and will splinter and break in more jagged patterns with breakage angles that are roughly 90 degrees (Villa and Mahieu 1991). This is a macroscopic clue that you are looking at post-mortem alterations, rather than a fresh bone break. Careful attention needs to be paid to the distinctions between fresh and dry injuries, so that trauma is not misidentified.

SWGANTH guidelines have been developed with the expressed purpose of creating stronger and more reliable trauma analysis. Ante- and perimortem are suggested terms for trauma analysis with the guidelines that characterization should be made on presence of an osteogenic reaction (ante) and fresh bone fracture patterns (peri). Discussions of post-mortem damage should be reserved for sections dealing with taphonomic analysis. SWGANTH cautions against the anthropologist offering up a cause of death and reiterates that mechanism of injury

(e.g. blunt force) and skeletal manifestations of injury are within the purview of the anthropologist. Cause of death and the discussion of soft tissue (except cartilage) are within the realm of the pathologist. In addition, where gunshot trauma is concerned, the anthropologist should not try to estimate caliber size from a wound or determine any features of a gun, as this falls under the jurisdiction of a ballistics expert. The term ballistics should not be used to refer to a gunshot wound, as it refers to features of firearms and their bullets, which is beyond the scope of anthropological analysis in this case.

SWGANTH also provides some additional guidelines of what not to do in a trauma analysis. Anthropologists should also refrain from referring to postmortem damage as postmortem fractures, as this confuses taphonomic processes with fracture mechanics. Incendiary language is also not encouraged as this can undermine the research and imply guilt (e.g. referring to an individual as a “victim” instead of a “decedent”). Most importantly, anthropologists must employ tested and reliable methods for trauma analysis, which can be upheld in a court of law. This is crucial if the testimony they provide is to be taken seriously and used judiciously.

## **Blunt Force Trauma**

Blunt force trauma is an injury or wound that results from the use of a broad or blunt instrument (see Figure 1). This type of injury produces a wound under the effects of tearing, shearing, and/or crushing. Examples of blunt instruments include a fist, baseball bat, hammer, and found objects, such as pipes. The forces at work with this type of injury can be characterized as direct impact, crushing, acceleration-deceleration, or sharp-blunt impact. The loads experienced during blunt force trauma can be low or high. Low force injuries occur when an



**Figure 1. Blunt force trauma to the skull.**

object hits a person, such as a wrench. High force injuries are the result of an object hitting a person, as during an explosion, or if a person is blown by a blast into a stationary object (Kimmerle and Baraybar 2008).

The mechanical properties of blunt force trauma will differ in relation to the area of the body affected (as bone composition and shape varies throughout the body), the size and shape of the weapon/object, the amount of force applied, and age of the individual. In particular, the age of the individual is important for cranial injuries as the vault tends to thin and increase susceptibility to fracture. In general, the overall distribution of injuries may shed light on the mechanism of injury. The key characteristics to analyze with respect to these injuries are location, length, width, shape, fracture type, and patterning of wounds. Depending on the shape of the instrument, there may also be a patterned injury that reveals the shape of the weapon (Kimmerle and Baraybar 2008).

When estimating the number and sequence of such injuries, it is necessary to distinguish the minimum number of injuries. *Puppe's Rule* is used to order the number of injuries. This rule states that fracture lines from subsequent injuries will terminate in preexisting fractures. By following the intersections of fracture lines, one can diagnose the sequence of multiple injuries. This is particularly useful among flat bones, such as the cranial vault (Kimmerle and Baraybar 2008).

Cranial blunt force trauma usually results in fractures that are depressed, radiating, comminuted, blowout, or basilar. Depressed fractures are characterized an in-bending of the bone away from the direction of force around the point of impact. There may be peripheral out-bending that occurs as well, depending on the force applied. If enough force is applied at the

point of impact, then the instrument will penetrate the bone, sending out radiating fractures from the point of impact. These fractures tend to move through areas of thinner bone that have less skeletal buttressing. In cases where a force causes a plug of bone to be inwardly displaced, one may also encounter concentric, or hoop, fractures that surround the impact site. Depressed fractures are also seen in the ends of long bones, as well as flat bones. These fractures usually occur when an object hits the bone. In contrast, when an individual falls or is thrown against another object, radiating fractures that originate at the site of impact and move outward are very common (Kimmerle and Baraybar 2008).

Mandibular fractures are usually the result of forces applied anteriorly or laterally. These forces may be anterior-posterior placed on the chin, or result from force being applied laterally on the mandible. The force required to fracture the bone is greater anterior-posteriorly, than it is for the lateral dimensions. Lateral force usually cause unilateral fractures, whereas anteriorly applied force can result in symmetric fracturing of the angle, body (posterior), condyles, and/or coronoid processes. In addition, whether the teeth are occluded or not affects the severity of injury, as an occluded mouth provides increased resistance to fracture (Kimmerle and Baraybar 2008).

Blunt force injuries to the hands and arms are common in cases where an individual is warding off blows or flying debris. An example of such wounds is the parry fracture, which is a complete, transverse fracture of the mid to distal third of the ulnar shaft (Kimmerle and Baraybar 2008).

## **Sharp force trauma**

Sharp force trauma (SFT) results from an injury with an edged object, or an object that is pointed (see Figure 2). These objects can produce several injury types, such as cuts, stabs, chops, saws, and crushing injuries. A cut occurs when an edged object is drawn across a surface, such as skin, and the resulting wound is longer than it is wide or deep. A stab wound results when an object comes into contact with a surface and the resulting wound is deeper than it is wide. Injuries, such as chops, may create an injury indicative of an edged blade, while also crushing the material it comes in contact with, thereby creating a situation where several forces are acting upon the injury site. For example, machetes are a type of weapon that commonly produce sharp force injuries, but also blunt crushing injuries, so they are often described as sharp-blunt trauma (Kimmerle and Baraybar 2008).

Sharp force objects can be divided into several broad categories that share similar wound characteristics. Short-light objects are objects, such as knives, that are used with one hand (generally) and produce wounds that are cut marks or saws. The weight of the attacker's body is the primary force behind the weapon and the morphology of the wound will depend on body positioning, angle of strike, number and pattern of strikes, composition of the bone, and any overlying soft tissue or clothing. The width and depth of injuries is correlated with the size of the blade. In contrast, long-heavy weapons, such as machetes and axes, can be used with one or two hands (generally) and result in sharp and blunt force features in the wound. The edges of a wound/defect will often experience fragmentation with this type of weapon. The swing required with most of these weapons adds increased force in the stroke and potentially greater damage at the target site. Weapons such as hatchets, fall into an intermediate category, but have wound



**Figure 2. A cut mark to the right horizontal ramus of the mandible.**

characteristics that are more similar to chopping injuries. Sawing injuries are also common with the force being applied in a back and forth, repetitive motion (Kimmerle and Baraybar 2008).

Identifying SFT requires the collection of data that pertains to wound morphology, number of defects, type of defect and their distribution. These wounds are often found in clusters, so care should be taken to identify the minimum number of potential cuts or blows. This will allow proper reconstruction of the events surrounding the creation of the injury (Kimmerle and Baraybar 2008).

## **Ballistic trauma**

Ballistic trauma results when skeletal tissue comes into contact with gunfire projectiles (see Figure 3). The compressive force of a projectile will often create a permanent cavity in bone, the morphology of which depends on both the projectile and the architecture of the affected bone. The threshold velocity needed to penetrate bone is 60 m/s, so any projectiles moving at this speed will exhibit ballistic force. Penetrating wounds are classified as those that enter the body. Entrance wounds have a wide variety of morphological that are generally classified into one of the following groups: circular, keyhole, gutter, tangential, eccentric, irregular, sideways, tandem, or double tap. The morphology of the entrance wound is affected by the size and shape of the projectile, the angle between the projectile and the target site, velocity, the distance of fire, the presence of any intermediate targets, and the properties of any affected tissues. It is possible for more than one bullet to enter at a single site, such as what is seen in tandem and double tap injuries. Entrance wounds will often produce radiating fractures that extend away from the entrance site toward the perforating (exiting) site. Linear fractures, in particular radiating and concentric fractures, are typically associated with entrance wounds that



**Figure 3. A cranial gunshot wound, specifically an exit wound.**

occur as a result of close- range fire, or medium and high velocity ammunition. Linear fractures and comminution may also be present at the exit site, as a result of heaving forces that develop due to intracranial pressure (Kimmerle and Baraybar 2008).

Perforating wounds are through and through shots that exit some portion of the head or body of an individual. They tend to be either regular or irregular in shape, with variation in morphology due to the biomechanical features of the exit site and the size and shape of the projectile. Generally, one will encounter more fracturing at the exit site, in comparison with the entrance site, though this is not always the case. Exit wounds tend to be larger than their associated entrance wounds due to the tumbling effects of the projectile and the fact that it is occurring at the maximum diameter of the permanent cavity created by the projectile. Whereas entrance wounds typically exhibit internal beveling, the opposite (external beveling) is true of exit wounds. They can also present radiating and concentric fractures. Wounds through thin bone, for example the orbits, may produce a large amount of fracturing that obscures the exit site, known as blowout fractures. If multiple injuries are present it is necessary to establish a sequence of injury if possible, as well as a minimum number of shots. This can be accomplished by interpreting the pattern of intersecting fracture lines. The morphology and pattern of fracture differs by anatomical region and care should be taken to document all associated injuries (Kimmerle and Baraybar 2008).

## **Fracture Types**

Many systems exist for classifying fractures, but all must take into account the strength, stiffness, elasticity, and composition of the bone at the affected area, which varies by anatomical

location. In addition, the size, shape, and applied force of any weapon used must also be considered. The most basic fracture classification is simple or multi-fragmented (comminuted), which can be further described with respect to position or location of the fracture(s), the completeness of the fracture, and fracture orientation. A simple fracture is t results in a break producing two bone fragments. As the name implies, a multi-fragmented fracture produces more than two bone fragments. Fracture types can be further subdivided from these basic categories (Kimmerle and Baraybar 2008). Sub-types of fracture include linear fractures that run parallel to the main axis of the bone, and transverse fractures which run perpendicular to that axis. Concentric fractures extend circumferential lay from a point of impact and are common in the cranium. Radiating fracture extend away from a point of stress as a force dissipates across the bone. Fractures can also be categorized by location within the body (Kimmerle and Baraybar 2008).

The skull is a common location for fracturing and many cranial fractures tend to be depressed, radiating, linear, comminuted, blowout, or basilar. Fractures to long bone will affect the areas around the joint, or those areas that lie outside the joint. Joint fractures are usually linear, comminuted, or impacted, whereas extra-articulate fractures are usually linear, comminuted, or segmental. Linear fractures can be broken down further by direction of force and comprise transverse, oblique, and spiral fractures. A special class of comminuted fracture may also be seen that produces at angular wedge of bone, often referred to as a butterfly fracture (see Figure 4). Compressive forces can result in depressed or crushing injuries; these can sometimes be seen in the vertebrae, head, and ribs. Therefore, body location should be taken into consideration when classifying fractures (Kimmerle and Baraybar 2008). A more detailed discussion of selected fracture types is presented.



**Figure 4. A butterfly fracture of the left femur.**

## **Depressed Fracture**

These fractures are primarily seen in the skull and are caused by direct blows, which cause a caving-in of the associated bone (see Figure 5). The size of the defect depends on the size of the impacted area, as well as the velocity of the force. Many cases involve only the outer table of bone, though the inner table may also be involved with occasional, incomplete fracturing. Fractures are often due in part to the rapid accumulation of compressive forces that feed an eventual collapse of trabecular or porous bone. Depressed fractures can also be seen in other areas of the body, such as the tibial plateau, where compressive forces can diminish the integrity of underlying trabecular bone (Galloway 1999).

## **Transverse fracture**

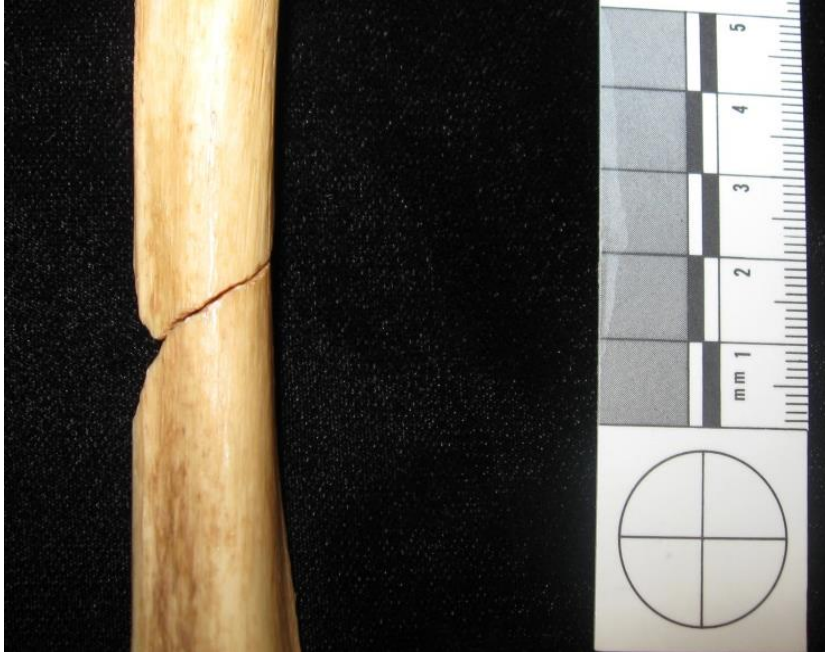
Transverse fractures can be determined by their orientation with the long axis of the bone. These fractures tend to run at approximate right angles to the long axis of a long bone, and can be propagated in three-point loading situations. In general, bone will undergo tension along the convex side and will experience compression on the concave side. As bone is strongest in compression, the convex side is the first to yield and results in the initial crack propagation (Galloway 1999).

## **Oblique Fracture**

These fractures track diagonally across the diaphysis of a long bone at what is usually a 45° angle (see Figure 6). They often result from the combination of compressive forces and angulation applied by moderate force. A common situation that leads to this type of fracture is



**Figure 5. A healed, depressed fracture of the frontal.**



**Figure 6. An oblique fracture of the femur.**

that it initiates as a transverse fracture, however following the initial break, tensile and compressive forces are increased on the remaining bone. This amplification of forces results in shearing as compression forces the remaining bone downward. Therefore, the initial portion of the fracture is perpendicular to the long axis of the bone, whereas the latter portion is oblique. The proportion of transverse to oblique portions of the fracture is determined by the magnitude of tension and compression. Oblique fractures can also be created in situations that comprise a combination of angulation and rotation in the forearm and leg. These paired bones (ulna/radius and tibia/fibula) act in a similar way to a spiral fracture. The bones experience oblique fractures at varying levels (Galloway 1999).

### **Spiral Fracture**

In this type of fracture, crack propagation follows the peak of tensile loading around the bone. When experiencing rotational forces, tensile stresses in bone are usually oriented at a 40-45° angle to the long axis of the diaphysis. These forces are greatest at the surface of the bone and at zero along the axis. Alternately, the compressive stresses are greatest at 180° to the tensile stresses, though they are also greatest at the surface and at zero along the axis of the bone. Fractures will begin at the point of maximum tensile forces and will follow the angle of rotation at about 45° until the two ends of the fracture are roughly one above the other. At this point, a longitudinal crack will often appear and unite the two ends. This is a fracture type that is commonly seen as a result of the application of low velocity forces (Galloway 1999).

## **Comminuted Fracture**

A comminuted fracture occurs when there are more than two bone fragments produced by an injury (see Figure 7). In the lower extremity, a butterfly fracture is more commonly seen than other areas of the body. This involves a triangular wedge of bone separating from the diaphysis. Pedestrians hit by motor vehicles may manifest this type of comminuted fracture. When the diaphysis is separated from the proximal and distal ends of the bone by multiple fractures, then the intervening portion is called a segmental fracture (Galloway 1999).

## **Linear fractures**

These fractures are often found in the skull and are the result of out-bending of large, thin portions of bone, which occur as a result of a direct blow at high velocity. They are usually the result of indirect trauma, but may extend to fractures that originate at the impact site (Galloway 1999).

## **Fractures of the Cranial Vault**

In the cranial vault, 70-80% of fractures are linear, 15% are depressed, comminuted, or stellate (star-shaped and consist of multiple radiating linear fractures), and 5% are diastatic (run along suture lines) (Galloway 1999).



**Figure 7. A healed, comminuted fracture of the proximal humerus.**

## **Fractures of the Ribs**

These fractures tend to be of the transverse or oblique types. Transverse is the most common type and usually occurs due to direct blows to the chest. Oblique fractures are created in situations involving crushing, bending, and grinding, such as motor vehicle accidents, and falls from a height. Oblique fractures are often concentrated on the lateral curvature of the ribs (Galloway 1999).

## **Fractures of the Sternum**

Commonly, direct blows at the sternum lead to transverse fractures, which are often seen in motor vehicle accidents. Vertical, longitudinal, and chip fractures are sometimes seen, but much less commonly (Galloway 1999).

## **Fractures of the Clavicle**

Clavicular fractures often result from falls onto an outstretched hand. In these cases, the position of the arm helps to determine the fracture pattern. Forces are more likely to be transmitted to the clavicle in scenarios where the arm is positioned to the side at impact. There is also a correlation between sternal fractures and age, with fractures of this area increasing in individuals over the age of 70 years. Injuries to the acromioclavicular joint are also common and occur most frequently in sporting activities, followed by motor vehicle accidents, and falls. Most cases display fractures of the middle third, with usually transverse and complete fracture types (Galloway 1999).

## **Direct vs. Indirect trauma**

Direct trauma is localized to the point of impact on the bone. These may manifest as “tapping fractures” that involve a small force moving at a slowing momentum, which often display as transverse fractures, though they may be obliquely transmitted. Crush fractures are another type of direct trauma that involve a large force spread over a large area and may manifest as transverse to severely comminuted fractures. Conversely, indirect trauma results in fractures outside the area of immediate impact. These fractures can be made by tension, rotation, and angulation (Galloway 1999).

## **General Methodology in Trauma Studies**

The most common approach to the majority of the studies under the heading “Patterns and rates of trauma” is to calculate the frequency or rate of injuries (e.g. fractures, lacerations, etc.) and then to analyze them based on sex, age, ancestry, socio-economic status, among other categories. The literature in this section can be further divided into studies that are looking at skeletal trauma in modern and past populations and those that are looking for intentional trauma of any kind- primarily in modern populations (e.g. domestic violence literature).

As concerns the first category (those looking at skeletal trauma), the vast majority are looking at long bones and are using the criteria set forth by Lovejoy and Heiple (1981) or some modification of these criteria. Lovejoy and Heiple (1981) looked at the long bones from the Libben Site in Ohio and divided them into thirds in order to analyze and describe skeletal trauma. In addition, they generally considered a bone complete if there was 75% or more

present. This seems to be a common means of discussing long bone trauma in these studies, especially among anthropologists (Walker 2001). In later studies, such as Judd (2002), the authors continued to analyze the diaphyses in thirds, but separated the metaphyses and epiphyses, as injuries to these locations could result from differing responses to biomechanical forces. These decisions seem well-founded, as the diaphysis is primarily composed of cortical bone, whereas the ends of long bones have a thinner cortical covering with varying amounts of trabecular bone underneath. These differences in material properties result in differences in structural properties at these locations. In particular, as cortical bone is stiffer than trabecular bone (i.e. has a higher modulus of elasticity), it may have increased strength at a particular location and be able to withstand different loads in different directions. In contrast, trabecular bone has a greater potential for post-yield deformation, which allows it to respond differently to microcracks in various loading situations, so the long bone ends do display different properties and probably should be separated in any analyses (Doblare et al. 2004; McKinley 2003).

As concerns the modern literature, there is a great deal of energy put into intimate partner violence and osteoporosis studies. These and modern intentional violence studies have a tendency to gather data from hospitals and trauma centers (Brink et al. 1998; Elliott-Brown et al. 1998; Sanders et al. 2002). The advantage is that usually injuries are diagnosed by a doctor and may have accompanying radiographs. In addition, some of the osteoporosis studies rely on interviewing patients about past and present fractures, as do the studies of intimate partner violence. The disadvantage to a survey method is that you only get the individuals who present themselves at a care center and this may not be reflective of the population as a whole. In addition, some of the research on falls (Guyomarc'h et al. 2009) relies on case studies, and while these are instrumental in exploring varying mechanisms of injury, they do not always represent

the typical injuries that are encountered by forensic professionals. This can lead to a more anecdotal, rather than instructive, value in some cases.

The statistical methods that are employed are varied, however, especially with fracture studies (Angel 1974; Lovejoy and Heiple 1981, Walker 2001), and there appears to be an emphasis on determining the fracture frequency or rate in a defined population with associated t-tests to look for differences in mean frequencies. Fractures are usually presented by individual or by bone, depending on the question of the researcher. For example, Brink et al. (1998) was concerned with fracture frequencies and location of the injury by sex and age. Other studies look for frequencies by element (e.g. Bacorn and Kurtzke 1953; Iida et al. 2003). A smaller number of studies, employed chi-square statistics (e.g. Lyons et al. 2003). These statistics generate an expected frequency based on the data, and compare the observed counts to the expected counts and look for significant deviations (usually at the 0.05 alpha level in most studies). These researchers usually employ a Yates correction that helps to identify where the significant differences are, but you must go back to the original expected and observed counts to see what direction the difference represents. These types of tests are popular, as they perform well on counts and can also handle categorical variables, such as sex, ancestry, and age classes with non-normal distributions.

In contrast to the modern literature, cases of early trauma suffer from gaps in skeletal collections and the effects of taphonomy that can cause under- or over-reporting. In cases of archaeological trauma, there is a potential issue of under- and over-reporting, as estimates vary widely throughout the literature. Moraitis and Spilioupou (2006) address this issue. They claim that some studies under-report trauma, since they record trauma by individual rather than by element. This masks multiple injuries in these studies. There may also be peri-mortem injuries

that do not have any associated skeletal reactions that remain unidentified, or are potentially obliterated by taphonomic processes. Additionally, these processes can also appear to be trauma, “pseudotrauma,” and may cause over-estimates in samples that have a larger time depth and exposure to varied taphonomic processes (Calce and Rogers 2007).

For example, some individuals may think that the cracking that accompanies the weathering process of long bones may be indicative of fractures. This would be an incorrect assumption and researchers could tell the difference by noting that weathering cracks follow the direction of osteons (i.e. they are longitudinal through the long axis of the bone), as well as paying attention to the fracture outline, edge, color, and angles, among other factors (Villa and Mahieu 1991; Sauer 1998; Wheatley 2008). In addition, the weight of the soil on an element may also cause it to break and deform, as if it had experienced plastic deformation due to a traumatic injury. This can also be discerned, as soil bending tends to be more exaggerated than that caused by a traumatic injury. Animal scavenging can also be mistaken for cut marks in archaeological remains. The artifacts of animal activity are usually found at the marrow-rich ends of long bones and are characteristically parallel lines that represent a tooth being dragged along the surface of the bone. Many, though not all, will be perpendicular to the long axis of the bone (Moraitis and Spiliopoulou 2010).

There are some taphonomic processes, however, that can completely obliterate signs of trauma, so that true estimates are never confidently known in some cases. Calce and Rogers (2007) investigated what processes had the potential to disguise blunt force trauma in skeletal remains. They found that the freeze-thaw cycles of some regions have the ability to degrade skeletal remains (i.e. fragmentation and in-bending of cranial bones) and obliterate signs of trauma. In addition, rain, snow and soil also had the ability to disguise blunt force trauma. In

the case of archaeological remains, they may have been exposed to countless numbers of these cycles, so the true number of traumatic injuries may be impossible to determine in some cases. The problem of over- and under-estimates is unfortunately not isolated to archaeological remains (Calce and Rogers 2007).

The modern literature on domestic violence also suffers from under-reporting of traumatic lesions due to a multitude of factors. Shepherd et al. (1990) found that the majority of individuals who suffer from intimate partner violence (IPV) do not seek medical attention, and even fewer label it as IPV. In fact, only 12-17% of those reporting to a medical center had their IPV injuries documented as such. Muelleman et al. (1996) note the same phenomenon and add that most individuals are afraid to report their injuries due to threats, embarrassment, or the stigma presented by the general public. Ellsberg et al. (2001) also noted that collecting information about IPV is fraught with ethical issues and that individuals who administer such surveys should be aware of the emotionally charged issues inherent to this research. In addition, modern intentional injury studies of any population are hampered by the fact that a lot of data are collected from hospital sites. This may also under-represent the true frequency of trauma in a population, as many cases go unreported for financial reasons, or because they are deemed trivial injury and may be referred to a family physician (Shepherd et al. 1990). Therefore, the data collected from hospitals may not truly represent the population at large.

In closing, the trauma studies presented on this list are chiefly concerned with reporting trauma frequencies. Anthropologists tend to focus more on skeletally recoverable elements, like long bones and crania, whereas the modern clinical literature focuses on fractures, as well as soft tissue injuries throughout the body. Several studies go beyond the mere reporting of frequencies and present t-tests and chi-square analyses that allow for significant differences to be found

between groups. Despite the care and effort made in data collection, the possibility of under- and over-reporting data in trauma analyses is still a potential problem. The best way to guard against these issues is to be explicit about the criteria you are using to determine fresh from dry trauma, as well as showing how taphonomic variables have been considered and assessed within the study.

### **Falls in the elderly**

Falls are problematic in the elderly, as increased bone fragility and decreased coordination can lead to serious injury from even a standing height fall. In fact, falls are the leading cause of nonfatal injury in individuals age 64 and older (Gelbard et al. 2014). As these individuals are more likely to fall at home, it is important to understand risk factors and the skeletal patterning of falls in order to prevent future injuries, and discern what circumstances have led to fatal falls. Gelbard et al. (2014) looked at ground level falls (less than 4 feet) versus falls from a greater height. They found that on average most falls occurred in the home, at ground level. In addition, non-ground level falls tended to occur from stairs, rooftops, and ladders. The authors have suggested that as the non-ground level fallers tended to be younger and in a residential setting, that this type of fall might result from more do-it-yourself projects being performed around the home later in life. Patterns of injury show that 2.5% of the sample (n=400) had skull fractures and 21.5% had lower extremity fractures. More specifically, those who fell from greater heights also experienced more facial fractures, more rib and scapula fractures, as well as more humeral fractures (Gelbard et al. 2014).

## Free Falls

The World Health Organization has determined that falls are the second leading cause of accidental injury death globally (WHO 2015). The height of a fall is integral in understanding injury patterns as velocity coupled with body mass determines the kinetic energy of the fall (Petaros et al. 2013). Petaros et al. (2013) looked at 179 cases of falls from variable heights and conditions and outlined some important factors to consider when determining the nature of a fall. Falls included those that were lower than 1.5 meters, standing height, impacts with deformable surfaces (i.e. snow, sand, and water), rolling falls, and falls from unknown heights. Seven body regions (head, neck, shoulder blades, upper extremities, thorax, pelvis, lumbar region, and lower extremities) and three body areas (upper body- head and neck; middle body- torso, shoulder blades, and upper extremity; and lower body- pelvis and lower extremity) were defined for this study. Fall heights were grouped into four categories: 1.5-3.5 m, 4-10 m, 10.5-30 m, and >30.5 m. The sample included 96 suicidal jumpers and 83 accidental falls with median heights of 17.5 m and 5 m, respectively (Petaros et al. 2013).

Patterns of injury for the total sample show that rib fractures were most common, followed by the head, spine, lower extremity, upper extremity, and pelvis. In particular, thoracic and extremity fractures increased with increasing height. In reference to the cranium, falls from less than 10 m generated more occipital, parietal and temporal fractures. In contrast, falls from over 10.5 m have more frontal, parietal, temporal and occipital fractures, in that order. Lumbar fractures were only present in 15% of cases and 67% of those were at heights greater than 10.5 m. Bilateral rib fractures increase with increasing height. Sixty seven percent of rib fractures were unilateral in falls at 10m or below. Lower falls also produced more rib fractures along the

axillar line. Higher falls generated rib fractures that were mammillary or paravertebral (Petaros et al. 2013).

The ribs aren't the only element whose fracture patterns were affected by the height of the fall. Both lower and higher falls generated unilateral pelvic fractures, as well as fractures of the pubis. Increased height, however, is correlated with more iliac and acetabular fractures. At lower heights, there are increased lower arm and lower legs fractures, rather than fractures to the humerus or femur, which are seen with higher falls. In leg fractures, the principally affected areas were the proximal femur and the distal portions of the lower leg. Arm fractures affected the elbow most commonly, followed by the lower arm. Overall, there was a significant relationship between height of the fall and the number of body regions affected, with higher falls resulting in more widespread injury. In lower heights, a greater portion of the sample had injuries localized in the upper and middle body, as compared to the higher fall groups (Petaros et al. 2013). Suicidal falls also showed more fractures to the thorax, extremities, and pelvis than accidental falls, but those differences disappear when compared across height groups, indicating that the height of the fall might be more predictive of fall trauma. Suicide victims did, however, show more bilateral extremity fractures, as compared to accidental fallers (Petaros et al. 2013).

In general, height is the major factor determining pattern and extent of injuries in fatal falls. The thorax was the most affected body region followed by the head. Linear fractures were more common at less than 10 m, while comminuted fractures were more common in longer falls. Feet-first and side impacts may be the most sensitive to the height of the fall. Feet first falls are described as the most common and may be more common among suicidal jumpers, which may explain the bilaterality of injury. Feet-first impacts can lead to anterior pelvic ring fractures, with posterior fractures seen at greater heights. In addition, secondary impacts due to bouncing,

or hitting other objects may also obscure the injury patterns, so care must be taken to make a thorough assessment of the injuries (Petaros et al. 2013).

## **Suicidal Falls**

Suicidal jumps may differ in injury patterning compared to accidental falls, as the subject may have greater control over their starting position at the onset of the fall. Biomechanical factors that affect trauma patterns of a fall include height, velocity at impact, and body orientation. Biological variables that that may possibly impact the distribution of trauma include sex and age (Abel and Ramsey 2013). Abel and Ramsey (2013) have conducted research on trauma patterns and suicidal bridge jumpers in the Charleston Harbor. Within this study, 27 individuals were found to have jumped to their death during the study period with 67% dying by drowning, 26% by blunt force trauma to the chest, and 7% by blunt force trauma to the head. The horizontal body position was found to incur the most injuries. Thorax trauma accounted for 63% of trauma and mostly involved the ribs, followed by craniofacial trauma at 37%. Eighteen percent of victims had upper appendage trauma and 15% presented trauma in the lower appendages. Cranial only injuries were indicative of a head-first entry into the water. Specifically, the ribs were most often serially fractures, which is characteristic of bridge jumps. In comparison, accidental falls tend to present more cranial and upper extremity trauma. Intentional jumpers tend to land on their feet more often, which may explain this phenomenon.

## **Anterior abdominal stab wounds**

Abdominal stab wounds are often the result of self-inflicted injury and assault. Studies have shown that in some areas self-inflicted abdominal stab wounds make up 1.6-3% of cases (Banerjee et al. 2013, Venara et al. 2013). Though these are fairly infrequent, it is important to be able to identify self-inflicted wounds from those encountered in assaults. It is interesting to note that in 59-61% of some cases the penetrating abdominal wounds were secondary to blows made with a knife. Knives are used in 80.5% of self-inflicted penetrating wounds, with the abdominal area as a target in 36% of the cases (Venara et al. 2013). Venara et al. (2013) compared assault wounds with self-inflicted injuries and found that knives were used mostly in self-inflicted injuries (as well as one wood chisel), whereas assault provided a greater range of weapons, including knives, a screwdriver, and broken glass. The upper abdomen is a frequent location for these injuries, regardless of manner of death, however self-inflicted wounds show a 20% incidence of anterior abdominal injuries. Lower extra-abdominal injuries tend to be less common in self-inflicted stabbings (Banerjee et al. 2013, Venara et al. 2013). Some studies have shown that suicides produce more wounds with a horizontal axis, whereas a vertical axis is seen in assault. In addition, there tend to be more wounds when an individual is assaulted in public, or at home with self-inflicted injuries (Venara et al. 2013).

## **Archaeology and craniofacial trauma**

In archaeological samples, some of the differences in injury patterns present between the sexes may be accounted for by the division of labor characterized by each group. For example, in rural archaeological communities in Croatia, men tended to have more physically demanding

work related to farming and women were more involved with milk and textile processing (Slaus et al. 2012). Men had higher craniofacial injuries with the frontal most affected, though the nasals were also a common site of injury. There has also been evidence of perimortem injuries due to sharp force trauma from weapons, such as swords and knives, which tended to be clustered in the upper third of the body, especially the head and neck. Craniofacial injury was also present in South Africa during the Stone Age. Depressed fractures of the parietals and frontal have been seen and are consistent with digging sticks known to be used by the populations studied (Morris 2012).

## **Australia**

The U.S. is not the only area of the world to experience increasing rates of fragility fractures; indigenous Western Australians have shown an increase in the incidence of hip fractures in adults over 40 from 1999-2009 (Wong et al. 2012). These fractures include those at the neck of the femur, pertrochanteric, and subtrochanteric regions. This is in sharp contrast to non-indigenous populations, which are experiencing a decline in the incidence of these fractures, highlighting how inequality of health care and prevention can have a substantial effect on the incidence and prevalence of these fractures (Wong et al. 2012).

## **United States of America**

The causes of trauma in the U.S. are varied, but some have suggested that lower socioeconomic status and geographical transience may be contributing factors. There appears, however, to be more evidence for lower socioeconomic status as a driver for traumatic injury than geographical transience, especially as it relates to intentional violence and the associated traumatic injuries (Feero et al. 1995; Kennedy et al. 1996).

The type of trauma, whether intentional or accidental, can also vary by region. When looking at intentional injury in community hospitals, Luna et al. (2001) found that assault accounted for 85% of cases in Spokane, Washington regional trauma facility. Gunshot wounds and stabbings represented 2/3 of the cases reported. In comparison, a trauma center in South Central Los Angeles, showed that among intentional injuries, gunshot wounds represented 71% of cases and stab wounds were 22% of cases (Elliott Brown et al. 1998). In addition, motor vehicle accidents dominated the majority of cases presenting unintentional injuries.

An individual's age may also predispose them to a certain type of trauma or injury pattern. Intentional injury tends to be experienced more commonly among the young. Several studies have found that younger individuals (16-35 years) tend to account for the most intentional injuries (Elliott Brown et al. 1998; Feero et al. 1995; Kennedy et al. 1996; Luna et al. 2001). In contrast, accidents have been found at various ages (Feero et al. 1995). Many studies have cited a male predominance in both accidental and intentional trauma (Elliott Brown et al. 1998; Feero et al. 1995; Kennedy et al. 1996; Luna et al. 2001; Odhiambo et al. 2013).

## **Africa**

A study by Odhiambo et al. (2013) highlighted similarities and differences in trauma types and rates among a population in rural Western Kenya, as compared to other areas of the world. As in other studies, the causes of trauma appear to align with gender, as most adults are involved with subsistence farming. Traumatic deaths were on the rise from the study years of 2003-2008. Trauma-related deaths in males were more prevalent in adolescents and young males. In contrast, trauma deaths were prevalent in older age females. It should be noted that both sexes presented a lot of trauma in individuals aged 65 years and over, though they were less

likely to die from intentional injury. In adult females, the leading causes of death were other injuries/poisoning and falls. The leading causes of male injuries were assaults and road traffic incidents. Suicides accounted for a smaller number of deaths with a clear male prevalence, as well as a preference for hanging. Road traffic incidents were also common with slightly over half among pedestrians followed by drivers/passengers. Accidental poisonings were also seen that stemmed from alcohol overconsumption and tainted local brews. Falls were more prevalent among older women and resulted in injury to the limbs, back, neck, and pelvis.

In general, women were more likely to seek treatment after an injury, but were less likely to receive formal hospital care. In addition, more females died at home than males. As this research was conducted via verbal survey of relatives after the time of death, it is possible that inaccuracy exists. As a demographic health survey reported that 25% of women had been violently abused in the past year, it is possible that intentional, domestic violence is being misreported. This situation may account for why so many women die of injuries that fall into “other injuries” and “unknown” categories. It may also account in some part for why more women tend to die at home. In contrast, trauma now equals HIV as a contributing factor for death among young males (Odhiambo et al. 2013).

## **Chapter 4: Cultural Aspects of Trauma**

This chapter will deal with the cultural dimensions of violence and how it can be expressed in both physical and non-physical forms. This helps to inform why the patterns of violence and injury may exist in a particular form among different groups, i.e. age, sex, and ancestry categories. Violence has a tendency to be conceptualized as a static, unchanging force with a focus on its physical and public expressions. The truth of the matter is that the concept of violence is dynamic and changing and it forms more of a continuum as Scheper-Hughes and Bourgois (2004) have envisioned it. It encompasses the public and private, the physical and emotional, the visible and invisible elements of aggression and is constantly producing and reproducing itself via gendered hierarchies and the processes of states that privilege some citizens or groups over others (Hume 2009). This analysis will analyze violence in its direct, political, structural, cultural, and symbolic forms, and the effects it has on those who create and shape it, as well as the differing experiences of those who encounter it. These divisions of violence should not be understood to reflect static, mutually-exclusive aspects of aggression. Rather they will be presented as nodes within an inter-locking network, producing and shaping one another in explicit and implicit ways. Lastly, I will argue that anthropology has contributed much to studies of violence/aggression and presents a means of reshaping how we view violence and how we envision and practice its protection/prevention (e.g. through the establishment of human rights) and what efforts can be pursued in the future to ensure that the violence experienced by citizens around the globe is identified, ameliorated, and challenged.

## **Direct Violence**

Galtung (1964) defines direct violence as physical harm enacted by one individual or group against another individual or group. This is an event, rather than a process, and is temporally defined as such. Bourgois (2001) has also defined direct violence as the interpersonal aggression that most laypersons would consider to be violence (i.e. disputes, fights, etc.) and refers to it as everyday violence. This form of violence can be culturally determined, especially as hand-to-hand fights often mimic the sporting events that are popular in a particular region. Brickley and Smith (2006) have shown that early twentieth century cemetery collections display metacarpal (i.e. the bones in the body of the hand) fractures that are consistent with the injuries sustained by boxers at the time. In addition, modern populations have metacarpal injuries that reflect the current style of boxing, i.e. holding the fist with the back of the hand up- whereas earlier styles had the fist held vertically, thumb up). In short, the way populations experience controlled, sanctioned modes of violence affects how they perform acts of direct violence in everyday life. This also has the potential to predict mechanisms of injury in current forensic analyses. The experience of direct violence, however, can vary depending on the potential target.

The ways that men, women, and children experience direct violence is varied, though the mechanisms of injury can be similar. Men in societies that are plagued by intra- and inter-state conflict tend to form the largest number of combatants (Jones and Ferguson 2006). This form of direct violence is expressed as gunshot/projectile injuries, sharp force trauma, and blunt force trauma (Kimmerle 2004). This results in a disproportionately large number of men being killed in intra- and inter-state skirmishes, as well as everyday street violence (Hume 2009; Jones and Ferguson 2006). In contrast, women combatants also suffer similar injuries as a result of

conflict; however, women civilians are often targeted by direct violence in ways that men are not.

Jones and Ferguson (2006) have shown that the disproportionate number of male deaths have resulted in a sex differential in the population which has likely increased the number of consensual unions, rather than marriages. Flake and Forste (2006) have shown that cohabitation outside of marriage is linked to increased incidences of domestic violence. The disproportionate effect of the direct violence on men is therefore affecting the way in which men and women interact, as well as female security in the home. Jones and Ferguson (2009) expand on this argument by showing how the Nash Bargaining Solution can be used to analyze this violence. The NBS states that the individual with the better fallback position is in the position to reap more of the surplus of rewards. In interpersonal relationships, this means that if men have more opportunities for political involvement, more interpersonal connections, and are more economically stable (which is guaranteed by their dominant position as framers of women's perspectives- symbolic violence), they will have a better fallback position. This in turn allows them to direct the behavior of women and limits the options available to women who experience domestic violence as a condition of their inferior fallback position. This creates a cycle of violence from which women have few options for escape (Jones and Ferguson 2009). This may also help to explain why many women do not present to local medical centers when injured intentionally (Sheridan and Nash 2007). The violence may be viewed as a private problem, aided by culturally-determined modes of symbolic violence.

This interface between direct and symbolic violence is also visible at the national level, as state institutions have subscribed to a masculinist ideal that separates the public from the private domain. This has rendered many forms of violence against women as invisible, or to be

labeled as something other than “true” violence (Hume 2009). Domestic violence has a disproportionate effect on women, though men can be and are often victims. Flake and Forste (2006) identified several characteristics of domestic violence in Latin American countries that are predictive of domestic violence which include cohabitation, female-directed decision making, and partner alcohol use. These characteristics are predictive (along with family size, socioeconomic status and education-level disparities in some other datasets) of environments that foster direct violence toward women. These patterns are similar to those seen in the US and other European countries, such as Switzerland (Flake and Forste 2006).

In addition, rape is also a common form of direct violence that disproportionately affects women, and rarely leaves any telltale marks on the skeleton. Das (1996) has shown that in India during the Partition, the kidnapping and rape of enemy women (i.e. Muslims) was a common practice. The violation of enemy women was equated with violation of the enemy state and women’s bodies were the landscape upon which the conflict inscribed the effects of direct and symbolic violence. At the end of this conflict, the return of enemy women was begrudgingly performed by both sides (though not all women were returned) and these women had to renegotiate their status within their native society. Rape has been an effective tool of individuals and states in order to shame, violate, and decimate the morale and population of the enemy. This form of suffering is unique to women, in that male violence is usually performed publicly and has clear laws governing its conduct, while this violence is often left as a matter to be dealt with privately. In addition, it often leaves no permanent marks on the body, which allows for claims of rape to be disputed. The division of public and private has left these more personal forms of female-focused violence largely unreported and lacking legal protection to ensure that they do not continue. The stories of rape survivors are routinely left out of truth commissions, as the

direct violence of men is privileged over that of women (Hume 2009). Overall, despite the fact that direct violence is sometimes correlated with political violence; several authors are able to illustrate a distinction between the two.

## **Political Violence**

Political violence is defined by Bourgois (2001) as violence perpetrated in the name of a political ideology. This type of violence plays heavily on the concepts of state and nation. For example, Hunt (2006) shows how the state in Colombia is often at odds with the rural concept of *el pueblo*. *El pueblo* is conceptualized as the symbolic ideal of the rural, agrarian communities that exist outside of Colombia's cities. It is often invoked by the state in nationalist agendas that aim to co-opt indigenous identities in an effort to present a unified nation of Colombia that serves the needs of the city elites while marginalizing the poor Colombian farmers. In fact, the state actually has little influence in rural communities, as the basic needs of the community are met internally without the sometimes much-needed assistance of the state. This power vacuum left by the refusal of the state to protect and provide for the rural communities of *el pueblo* leaves these areas vulnerable to groups that promote a particular ideology and usher in waves of political violence (Hunt 2006).

State and non-state actors in Colombia have been vying for control of these rural areas that are often resource-rich and the political violence is disproportionately experienced by the poor and indigenous communities. Petras (2000) notes that Colombian guerrilla groups, such as the FARC, originally sought to fill this power vacuum left by the state and promoted an agenda centered on agrarian reform and loosely linked to the Communist party. The democratic state

then targeted the guerrillas in these communities, in an effort to reestablish its right to control the power in the rural sphere. The consequences of these actions were borne by the peasant farmers and indigenous communities that were caught in the middle of the struggle. State armies and paramilitaries that were opposed to the ideology of the guerrillas launched attacks against any rural communities suspected of aiding the enemy. State officials attempted to mask the atrocities of the armies by glossing the language of violence with a technical veneer. For example, the armies often committed “false positives” which referred to the practice of luring young people from rural communities with the promise of food or money for some work and then executing them with firearms. These individuals were then staged with weapons to appear as if they had been combatants that the army had neutralized. This was done as a message to the community and was never identified by the state as murder, though it certainly should be considered murder (Meija 2011). The identification of this type of trauma can be accomplished by looking at the pattern and regions of the traumatic injuries. If analyses of the wounds are allowed, then a reconstruction of the injury can take place. Unfortunately, the marginalized position of these groups means that thorough analyses of this kind are infrequently accomplished (Kimmerle and Baraybar 2008).

Indigenous communities were often targeted, because their land was home to rich natural resources that the state and international communities wanted to control, thereby exacerbating political violence in these areas. The U’wa of Colombia attempted to restrict land use by mining and oil companies and found that there were increased paramilitary attacks on their communities (Gedicks 2003). In addition, the palm oil industry has forced many communities off of native lands that were granted to them legally (Oslender 2007). The increased activism of indigenous

communities and increased claims to land rights have exacerbated political violence and forced a change in how the identities of poor and indigenous groups are constructed.

The struggle for political rights has shaped how indigenous identities are formed and perceived, as well as contributed to increasing levels of political violence. The CRIC (Regional Indigenous Council of the Cauca) first formed based on class struggles for peasant farmers and advocated agrarian reform. This caused tensions at the national level, as the state was positioned against any struggles for class reform and contributed to increased paramilitary and army presence in these communities. The CRIC was forced to drop mestizo and Afro-Colombian members in an effort to claim indigenous land rights, since that was an agenda that was encouraged by the state, as it did not attack the current class hierarchy (Troyan 2008). Indigenous identity was then renegotiated to establish who could legitimately make claims to the land. The black peasant movement faced similar issues when Law 70 of 1993 was passed. This was the first time that a black identity was acknowledged as a part of the Colombian national identity, and it guaranteed certain land rights for these individuals. Although land claims were granted, it became obvious that state armies and paramilitaries were forcibly displacing communities located on resource-rich land and the state lacked the will or power to protect the newly established rights of these communities (Wouters 2001). This cross-cuts issues of structural and cultural violence, as they legitimize the use of force based on the identity of the intended target.

Political violence also has the power to reshape gender identities through their relationship with violence. Moran (2010) has noted that during times of conflict gender roles can experience dramatic shifts. Militarism, in an effort to cull all of the resources within a population, may allow for more fluid gender categories and grant additional rights to

marginalized groups, such as women in some societies engaged in wars. These advantages afforded during time of conflict are often hard to maintain in the post-conflict period. In many cases, the end of a struggle may usher in a wave of even more traditional and restricted roles for women, who may have enjoyed more rights in the pre-conflict period. Myths are often employed that exaggerate the conservatism of the pre-conflict period, in an effort to force women back into a less dominant role. The fluidity that they experienced during the conflict is now viewed as a challenge to the emergent government and social system (Moran 2010).

Though this was not explicitly discussed by Moran, her argument seemed to parallel the situation in the US during WWII when women were encouraged to seek employment outside the home to help the war effort. Many of these women lost their jobs once soldiers returned home and were expected to resume their role as mother/housewife, and any advancement they had gained were lost after the conflict period.

Myths are not just employed to restrict gender roles; they are also used by the state to legitimize its use of violence. Nagengast (1994) exposes the myth of the state as an ideal system with the sole power to employ violence in the name of the greater good. When a non-state actor challenges the state, this myth falls apart and reveals the inadequacies of the state to protect its citizens and exposes the possibility that it can be overthrown- one that is denied through the creation of the myth (Nagengast 1994). This works for states as well as shadow states, as an example from Colombia will demonstrate. Metelits (2009) researched the reasons why relationships between civilian communities and state and non-state actors change over time. They found that the presence of active rivalry can increase political violence. When the FARC was established in 1964 in Colombia (Petras 2000), they formed a mutually beneficial relationship with local communities from which they extracted resources. This was a long-term

strategy that benefitted both parties as communities provided resources and the FARC provided goods and services (Metelits 2009).

The situation changed in the 1980s, when the paramilitaries formed in response to the guerrilla groups, e.g. the FARC, and provided an active rivalry securing resources from the same populations. The FARC abandoned its long-term, mutually beneficial strategy for a short-term strategy, focused on raiding communities and violently interacting with the population (Metelits 2009). In short, the active rivalry had eroded their claim to the legitimate use of force and they responded by directing violence at the civilian populations, thereby appropriating the same force that they initially revolted against (Metelits 2009). The lack of state power allowed these tensions to foment and a comfortable impasse developed that allowed the violence to continue, as it benefitted both groups. Muller (1985) has shown that intermediate regime repressiveness results in the highest death rates among populations. As the paramilitaries and guerrilla groups vied for power in the void left by the state in rural areas, they created just such a situation that amounted in hundreds of thousands of deaths and millions of internally displaced individuals (Muller 1985; Nagengast 1994).

## **Structural violence**

Structural violence is defined as the process by which societal structures (e.g. political and economic institutions) are constructed to marginalize and discriminate against certain individuals or groups (Bourgois 2001; Galtung 1964). Scheper-Hughes and Bourgois (2004) speak of this in terms of everyday violence, since it is violence that permeates the everyday interactions of individuals within a population. Structural violence originates when individuals

in power structure the socio-political system to provide advantages to certain groups over others. Bailey (2008) shows how path dependence can construct such a system. In Colombia, where state power was always shallow and contested (Pardo 2000), individuals sought out their own avenues to secure resources, which lead to corrupt officials who created a government system that served the powerful and wealthy. Path dependence states that origins of states are critical in understanding their development and once a strategy has been adopted, changes to that strategy become less likely over time. Therefore, Colombia's state system that encouraged structural violence early on has not changed, because the people in power benefit from it and have a vested interest in keeping things the way they are currently structured (Bailey 2008). This system leads to inequalities between genders and indigenous and city-dwelling communities, to name a few.

Structural violence often leads to disparities in socioeconomic status among those who are privileged, and those who are not, whether we look internationally or at domestic populations. Links have been found between socioeconomic status and the incidence and mortality of injury (Lyons et al. 2003). In a Welsh study of hospital admissions, it was found that children presenting to medical centers exhibit more socioeconomic disparities in injuries than older adults (Lyons et al. 2003). In both children and older people, affluent individuals will experience less assault injuries. In children, there are more injuries due to self-harm, which not a pattern represented in the older age groups (75+). Additionally, deprived children are more likely to experience falls, pedestrian road traffic accidents, non-pedestrian road traffic accidents, poisonings, and burns than their affluent counterparts. This finding may be linked to the fact that lower socioeconomically positioned individuals have to negotiate a more dangerous external environment (Lyons et al. 2003). Differences may also exist in reference to sex and gender for certain injury types. Gender inequality is a by-product of the structural violence inherent to

many countries including Colombia. Women are subjected to direct violence (e.g. rape and interpersonal assault) and few laws protect them and even fewer are regularly enforced (Caprioli 2005; Confortini 2006). Shepherd (2007) has shown that gender inequalities are a reflection of imbalances in power structures and that global security depends on gender security, which can never flourish in an environment of structural violence. Changes need to come from the state-level, though this has often been the source of structural violence. Moussa (2008) argues that global security is intimately linked to gender security and if current international policies do not provide for marginalized groups, such as women, then a truly effective international security will never be reached.

In addition to women, the indigenous communities of Colombia have long been victims of state-sponsored structural violence. Green (2005) notes that when the state allowed cheap exports into Colombia, this nearly destroyed the local agrarian community, which is largely comprised of minority and peasant farmers. This forced many to resort to cultivating coca crops in order to survive the economic fallout. Government forces then retaliated against these farmers in the drug war and pushed them further into the jungle and onto native lands. Gedicks (2003) highlights the fact that many coca crops were sprayed with pesticides that likely caused the farmers and indigenous groups health problems. Cosmo-Flux, which was created by MonSanto, is a pesticide that is meant to be dropped from no more than 10 feet in aerial sprays.

Government forces used five times the amount suggested by MonSanto and sprayed from a height of 100 feet raining pesticides on communities of coca growers and farmers with legitimate crops alike. Indigenous groups and poor farmers soon started complaining of health issues and the Colombian government and the US denied that the chemicals had been improperly used. Structural violence is easy to see once one recognizes that the peasant farmers were targeted,

rather than corrupt officials and landowners who have more of a stake in the corrupt government system. This has led to public policies that infringe upon the peasant communities right to health (Gedicks 2003).

Indigenous communities, as well as poor communities throughout Colombia, have also been subjected to forced displacements. The numbers of internally displaced people (IDPs) number in the millions and they are by and large comprised of indigenous and poor farmers (with a high number of women) who used to inhabit resource-rich land that has been appropriated by state-sponsored and international corporations (Gedicks 2003; Holmes and Pineres 2011). In the US, there are similar issues, as poor inner-city black women are unfairly targeted by government officials. James et al. (2003) has shown that these women tend to have their children taken more often, are more often visited by government officials, and are less aware of resources available to them than their white counterparts. This shows a systematic bias to keep these women at a lower social standing due to the fact that they are black women. This has also led to issues of symbolic violence, as these women internalize the discrimination and begin to believe that they deserve this treatment (James et al. 2003).

## **Cultural violence**

Cultural violence occurs when aspects of a culture are used to legitimize violence (especially the structural and direct forms) and make it “feel right” (Galtung 1990). A common form of this is to blame a victim of structural violence for casting the first stone (Galtung 1990). Galtung (1964) envisioned a violence triangle with direct, cultural, and structural violence on each point. The three types of violence network and interact with each other and you can always

flip the triangle and trace violence through each form and see the cascade effects on the other two forms of violence. Direct violence is represented as an event, structural violence is a process, and cultural violence is an invariant that helps legitimize the other two (Galtung 1964, 1990).

Cultural violence can employ cultural stereotypes to justify why violence in any form that is directed at a particular group is justified. To draw on an earlier example, Hume (2009) discussed how rape is a frequent form of direct violence that is directed at women. This becomes possible, because cultural stereotypes represent women as more submissive and weaker than men, which allows them to be viewed as objects to be placed under the protection, or control, of men. This stereotype relegates women to possessions and robs them of agency in their own lives. The fact that they are then treated as objects, without a will of their own, is justified by their weaker status. Poor women in particular, are especially vulnerable to cultural violence. James et al. (2003) studied the violence inflicted on poor, inner-city black women in the US. They found that due to racial stereotypes these women were more targeted by the police and had their children taken by child protective services, more than similarly matched poor white women. This violence was implicitly justified by the beliefs that they were somehow inferior mothers due to their race and it was justified to engage in hyper-surveillance (James et al. 2003). This treatment is not solely directed at women and other groups experience cultural violence legitimized by stereotypes.

In Cartagena, Colombia, racial, class, and gender stereotypes marginalize Afro-Colombians and lead to complex forms of cultural violence (Streiker 1995). Afro-Colombians are described as sexually promiscuous, animal-like, boorish, and wild. All of these stereotypes function to strip them of their humanity and allow for increased levels of violence against them.

This legitimizes the use of force and absolves the perpetrators of any wrongdoing, because these populations weren't considered full citizens anyway (Streiker 1995). Indigenous communities have also suffered under similar experiences with cultural violence and find that the sentiments are often internalized to the detriment of the community (Waldmann 2007).

## **Symbolic violence**

Bourdieu and Wacquant (2004 ) identify symbolic violence as the misrecognition of violence by those who have been dominated, in such a way that they become complicit in their own domination, fail to recognize violence as violence, and take on the perspective of the dominant group. This led to some groups internalizing the discrimination and actually believing that they are inferior and feeling helpless to change their social situation and respond to the various forms of violence that they experience (Hume 2009; James et al. 2003). This also creates a “grey zone” (Roy 2008), whereby the lines between victims and victimizers is blurred, which is clearly demonstrated in the intersection of symbolic violence and gender.

Bourdieu (2004) illustrates that a dominant male framework has been established that privileges the male perspective and forces women to conform to this framework when negotiating gender relations. Binary categories are established, such as public/private, masculine/feminine, war/peace to name a few that obscure the ability to conceive of alternatives when forming identities and shaping responses to violence and aggression of all forms. For example, a masculine/feminine dichotomy masks the fact that there are competing masculinities and femininities. Hume (2009) notes that many state systems seek to encourage a “man the warrior, woman the peacemaker”, dichotomy that symbolically robs certain groups of agency. If

all males are conceived of as combatants, then what happens to men who do not take up arms in conflicts? Carpenter (2005) has shown that these men usually slip through the cracks of aid organizations that prioritize aid to women and children, as they are seen as the true victims and non-combatants. This discounts men's ability to resist violent encounters, as well as masks the fact that women can also be human rights violators (Carpenter 2005; Hume 2009). The idea of a "pure" victim oversimplifies the situation and ignores the complexity and messiness that is found in conflict situations; it also functions to marginalize certain groups, e.g. male non-combatants (Creek and Dunn 2011). The symbolic violence of creating a public/private dichotomy can also contribute to the domestic violence that has been previously discussed. If only public violence is punishable, then private violence goes unchecked (Hume 2009).

The incidence of interpersonal violence is usually reported as higher for women than men in studies conducted around the world (Apel et al. 2011; Petridou et al. 2002). Females are disproportionately affected, though men are also victims of this type of violence. Apel et al. (2011) suggest that since many of the victims of interpersonal violence are young (i.e. younger than 40 years) and more likely to be injured at the hands of known acquaintances and family members, they are less likely to present to medical facilities. The symbolic dichotomy between public/private creates a situation where women may be blocked from access to treatment, or may be fearful of repercussions if the perpetrator is named to authorities. This symbolic violence may intersect with structural violence for some groups, such as black women. A study conducted in Philadelphia has shown that inner city women in an area with a median income of \$11,810 are at a higher risk for injury in accidental and intentional situations. About half of all patients seen at a Philadelphia hospital presented with injuries due to falls or intentional violence and reported no health insurance. Women aged 25-34 years had the highest numbers in both categories (i.e. falls

and intentional violence). Previous studies have shown that older women tend to incur the highest number of falls, so it is possible that some “fall” injuries may be masking intentional violence. As the home was the most frequent site of injury, the individuals with access to the private lives of the victims serve as the only potential witnesses, and as the most likely perpetrators. The same patterns were not upheld among men and indicate that private violence may be accumulating unchecked in this group (Grisso et al. 1991). The dichotomy between public and private also affects international women, especially victims of rape.

Das (1996) has discussed at length the toll symbolic violence takes on rape survivors of the Indian Partition, the chief evidence of which is silence. Das invokes the image of a river separating two shores: one the memory of past violence, the other the everyday lived experiences and the losses that are grieved as a result of that violence. Women who had been kidnapped and raped by enemy soldiers returned to a society that viewed them as a dishonor and an insult to the national psyche. In many cases, the women were killed by family members to spare them the dishonor to the family. For those women who endured, silence served a protective function as it spared them from having to relive the violence and becoming targets of family violence; however, their silence was also used by the patriarchal society to control how the past was remembered, as some injustices were not allowed to be discussed. The privileged male violence (e.g. a death on the battlefield) was publicly mourned and women were allowed to voice their grief. The private pain of the abduction, however, was not publicly mourned and was a source of shame meant to be borne by the women alone. Women referred to this experience as “drinking a poison” or in pregnancy metaphors, such as “a pain that cannot be born”, intertwining the silence and their bodies as the landscape of violence (Das 1996). The masculine framework that forces their pain into the private realm is a powerful example of how symbolic violence can trap the

dominated within the perspective of the dominant and shapes how people respond to violence (Hume 2009).

The war/peace dichotomy may be the most onerous of all, because it masks the violence that can characterize periods devoid of war, as well as limits the concept of peace to the absence of war (Galtung 1990; Fry 2007). Scheper-Hughes and Bourgois (2004) note that violence and aggression function on a continuum, this suggests that there is a sliding scale and even during “peace” there may be violence, usually in the form of structural violence. Hume (2009) adds that it is not unusual to see a rise in violence levels after a period of conflict. Violence may have become normalized through the conflict period and now permeates all levels of society. A chain can develop that fosters a cycle of violence and perpetuates Bourdieu’s “law of the conservation of violence.” As a hypothetical example: an indigenous peasant farmer experiences structural violence by the state that results in a marginalized role in society, he then engages in domestic violence at home with little fear of reprisal, as there are few laws against it and fewer that are enforced, his wife then experiences the direct violence of the beatings and the symbolic violence of her forced silence in a patriarchal society- violence begets violence. In other words, although a political state of peace may exist, it in no way ensures that issues of structural and other forms of violence are absent (Scheper-Hughes 2004). The dichotomy between war and peace thereby functions to mask the violence inherent to everyday life in a “peaceful” society, which foments future tensions.

This false dichotomy between war/peace also presents a limited view of peace, what Fry (2007) calls negative peace in that its only condition is the absence of war. On the flip side of the same coin, positive peace calls for a fulfillment of essential rights and basic human needs, along with an absence of war and structural violence. The concept of positive peace is much

more consistent with encouraging less future conflict, and provides alternative avenues for dealing with aggression and violence. This process of uncovering alternative avenues for dealing with conflict, as well as provisioning for future peace is an area where anthropologists stand to make a lasting impact (Fry 2007).

### **The future of violence**

The aspects of violence that have been previously discussed are not just Colombian, Indian, or American issues; they are issues that have global significance and cross-cut gender, age, ancestry, and class identities. The United Nations has tried to set an example and foster global accountability with the creation of a Universal Declaration of Human Rights, aimed at reducing multiple forms of violence, and fostering a more peaceful global community. The role anthropologists have played as concerns human rights will be discussed, as will ways in which anthropologists can contribute to theory, practice, and fieldwork associated with uncovering human rights abuses.

Anthropologists initially got off on the wrong foot with the UN Declaration of Human Rights (UNDHR) as a concern for the universality of these rights derailed anthropological involvement for several decades. Messer (1993) identifies some reasons why anthropologists were reticent to contribute to the research surrounding the human rights debate. First, there was a concern that rights are culturally relative and that universals may marginalize certain groups. This early criticism, voiced by Herskovits and Barnett (1948) among others was misunderstood to suggest that all is permissible under the umbrella of cultural relativity. This was not the case as cultural relativism did not equate with tolerance and researchers were most likely voicing a

concern that proper research discover cross-cultural essential as concerns human rights (Goodale 2006; Renteln 1988). Second, human rights theory was constructed primarily within a legal framework, which had the effect of marginalizing anthropologists. Third, the sensitivity of doing fieldwork contributed to reluctance, as some anthropologists feared that permissions to study specific groups would be revoked. Lastly, anthropologists have historically focused attention on small-scale societies. The human rights framework places the emphasis on state-level societies and this was incongruent with the way anthropologists were conducting research. Attitudes have shifted in recent decades and anthropologists are engaging in human rights research and the field has a lot to gain from their inclusion (Messer 1993).

As concerns theory, anthropologists can make several contributions concerning how we frame human rights discourse. Messer (1995) has suggested that anthropologists can use their skills to engage in cross-cultural research that seeks to discern common elements in human rights across the globe. Therefore, when a universal right is proposed, it will stand more of a chance of being a culturally-plural, essential right. Anthropologists can also research and help clarify who is and is not a citizen in different populations and how that translates into given rights. In addition, Messer (1995) also suggest that anthropologists can document how rights change through time to ensure that human rights stay current and have continued meaning to the global community. Goodale (2006) and Preis (1996) have advocated for human rights as a social practice. Much of the research into human rights outside of anthropology has concentrated on abstract rights formulations. Anthropologists have the unique ability to show how rights can be experienced and put into practice on the local level, which can help shape how we view these rights and recognize their ability to be dynamic concepts and practices. Sen (2004) has also suggested that human rights be opened up to public discourse. Anthropologists could then

analyze changing attitudes and how rights are shaped by the multitude of voices that contribute to the conversation. Lastly, Fry (2007) points out that human societies, especially simple hunter-gatherers, employ a range of redress options that do not require aggression and overt acts of violence. If we can explore these alternatives to violence, then we may be able to employ them in order to mediate tensions between states. In addition, Fry (2007) argues that war is not an old construction and therefore it should not be seen as the only alternative. Positive peace is a more legitimate way of provisioning for reduced future conflicts and the close monitoring by anthropologists can identify and challenge all forms of violence including structural violence (Fry 2007).

In practice, anthropologists can offer some new tools that can be utilized by human rights researchers that will expand and clarify our understanding of rights in general, and how they are formulated. Riles (2006) suggests that ethnography can be used for more than just cultural description, and can be employed as a tool in assessing how human rights are constructed by the fields currently developing them and how current frameworks succeed or fail. Riles (2006) details how in anthropology's absence from the debate, other fields have tried to appropriate ethnography to analyze the human rights (HR) framework with limited success. Anthropologists have a unique relationship with ethnography that allows them to effectively use it to critique the current HR framework and to reconcile the past and present as we develop and engage with HR research (what Riles calls 'circling back'). Cowan (2006) has also suggested that we re-conceptualize how we define culture, in order to acknowledge its dynamic nature and explore how culture and rights intersect and build off each other. There is a tendency to think of culture as a static concept and HR research reveals that this is not compatible with creating sustainable rights that are culturally plural and meaningful to a variety of fields and societies.

Anthropologists also have a duty to help ensure the protection of fellow scientists around the globe and to help ensure that their rights and lives are protected in areas of conflict. Stover and Eisner (1982) call on scientists from all disciplines to monitor the global situation and provide assistance, if possible, to scientists who are persecuted on the basis of their profession, involvement in activist and HR causes, and because their research might expose truths that are dangerous to people in power. Speed (2006) expands on this call to duty by encouraging a critically engaged activist research. Anthropologists should not only research how HR are employed across the globe, but should take an active interest in their monitoring and challenging abuses. Anthropologists' positions at the regional level and inside small-scale communities gives them unique access to decipher how these rights are employed and how they may be misused that is lacking in other fields.

As concerns human rights abuses, anthropology, forensic anthropology and archaeology specifically, can offer tools to help uncover and document abuses, so that the truth is exposed. Doretti and Snow (2003), as founding members of the Argentine Forensic Anthropology Team, have created a standard operating procedure that has been used in countless countries to systematically document and uncover evidence of human rights abuses. They propose a four stage procedure for anthropologists that includes 1) historical research into the conflict (can help identify mass graves, etc.), 2) the collection of ante-mortem data (such as dental records for identification), 3) archaeology (unearthing buried remains in a scientific manner- borrowing techniques from anthropology and forensics), and 4) lab analysis (identifying remains, documenting trauma, and creating demographic profiles of victims). The main duty of anthropologists in many cases is to unearth and identify remains, which involves the creation of a biological profile, trauma analysis and demographic profile of all the victims in a specific

context, so that their status as non-combatants can be confirmed (Burns 1998; Juhl 2005; Steadman 2005). Anthropologists are crucial to documenting abuses, because standard operating procedures with reliable and tested methods have been developed in anthropology. Early excavations that were not scientifically conducted resulted in destruction of evidence that cannot be recovered, so care must be taken to maintain the integrity of evidence collection (Doretti and Snow 2003; Kimmerle 2004).

In closing, anthropology's greatest contribution is most likely our ability to show that conflict can be resolved in many ways that do not employ the use of violence, and humanity has a remarkable ability to foster peace if the desire is there (Fry 2007). As an example, the Siriono and Paliyan (simple hunter-gatherer groups) rarely engage in violence and prefer avoidance, friendly peacemaking (mediation by third parties), or some form of community council to acts of violence. It is also important to note that these are fairly egalitarian societies with roughly equal respect for men's and women's roles. In a cross-cultural study of war, 9-28% of human societies rarely engaged in it, or did not engage at all (Fry 2007). This demonstrates that the potential for peace, like the potential for aggression and violence, is within us all. Violence comes in many forms both visible and invisible- and is dynamic, productive and destructive- therefore anthropologists must be at the forefront of human rights studies advocating for peaceful alternatives and the advancement of human security, as well as the identification of potential abuses.

## **Chapter 5: Materials and Methods**

### **Materials**

The samples for this project are derived from three sources: the William M. Bass Donated Skeletal Collection, The William M. Bass Forensic Collection, and the skeletal collection curated by Dr. Murray Marks at the Regional Forensic Center. All collections are located within Knoxville, Tennessee. Macroscopic skeletal analysis is used for fracture characteristics and location, and the sample includes individuals for whom age, sex, ancestry, and injury cause are known. Adults (age 18 and older) of both sexes and various ancestries were used for this sample as there is a pronounced skew in the Donated Collection toward older adults (see Table 1). In addition, it should be noted that these individuals are not a random sample from the overall population of the United States. The factors that lead an individual to participate in the donation program, or that result in their curation in either forensic collection, are varied and potentially unknown in some cases. As such, the patterns that may be present in this data may not reflect the larger population in all cases.

The William M. Bass Donated Skeletal Collection was chosen, because it represents a large sample of modern Americans. The collection was started in 1981 through the efforts of Dr. Bass to improve time since death research. The early years of the collection were characterized by donors from medical examiners, but a shift has occurred over the years, and now two-thirds of the individuals that are donated are done so by direct donation prior to death or through their families. Around 1500 individuals are curated within the collection and they represent birth years from 1892 to 2011, with most individuals having a birth year after 1940. Individuals from this collection represent 36 different states, with the majority of individuals from the Southeast,

**Table 1. Sample sizes for each collection with respect to ancestry and sex.**

<b>Collection</b>	<b>White</b>		<b>Black</b>		<b>Hispanic</b>	
	<b>Male (n)</b>	<b>Female (n)</b>	<b>Male (n)</b>	<b>Female (n)</b>	<b>Male (n)</b>	<b>Female (n)</b>
<b>UT Donated</b>	64	18	2	0	1	1
<b>UT Forensic</b>	25	17	6	2	3	0
<b>Regional Forensic Center</b>	43	12	5	2	1	0
<b>Totals</b>	132	47	13	4	5	1

specifically Tennessee. In addition, the majority of individuals fall within the age range of 40-75 years, with more than twice as many males as females, and a predominance of white individuals. Most individuals in the collection have a known age, sex, and ancestry. In addition to basic demographic information, recent years have broadened the amount of ante-mortem information that is collected for each individual. Currently, information on an individual's health, occupation, habitual activities, as well as other life history data are collected, in order to increase the utility of the collection across varied research topics (Personal communication, Dr. Lee Jantz).

The William M. Bass Forensic Skeletal Collection was the second collection under study. Individuals were chosen based on the presence of skeletal trauma as well as the presence of the affected skeletal material. The Forensic Collection consists of over 100 cases that were curated during Dr. Bass's tenure as State Forensic Anthropologist, which began in the 1970s. Many of the individuals in this collection have not been identified, though there are a small number of individuals who do have known demographic identifications. The individuals in this collection are predominately from the state of Tennessee (Personal communication, Dr. Lee Jantz).

A smaller skeletal collection at the Knox County Regional Forensic Center represents the third collection used for this study. This facility serves Knox County, as well as 27 surrounding counties. Dr. Murray Marks is the forensic anthropologist employed by the Regional Forensic Center, who has curated a collection of skeletal elements taken from a variety of forensic cases that have come through the Regional Forensic center during his time as forensic anthropologist. There is an emphasis on dental remains and trauma within the collection, which is primarily used for training purposes (Personal communication, Dr. Murray Marks). Individuals with trauma, as well the affected skeletal elements present, were selected for inclusion within this study.

Every effort was made to include all individuals with known trauma for the current study, but the samples were constrained by the knowledge of the injury event and the composition of each individual collection. The samples, when taken as a whole, show a skew toward white males. It should be emphasized that conclusions made by ancestry should be treated as tentative, as there are 17 total black individuals, and 6 total hispanic individuals. Ideally, representation for each group should be around 30 for the statistical analyses performed (Agresti 2007). Both groups fall short of the ideal sample size and the analyses may be suggestive of patterns seen in trauma among these groups, but they cannot be considered conclusive.

## **Methods**

Information was collected in three areas, demographics, fracture features, and injury features. First, demographic characteristics of individuals (i.e. age, sex, and ancestry) were recorded for each skeleton and entered into an Excel Spreadsheet for the statistical analyses. The identity of all skeletal remains and radiographs were unknown beyond the demographic categories assigned to each. These data allowed for comparative analyses of injuries over age, sex, and ancestry categories, in order to assess if there are differences in patterns and types of injuries within and among groups. The demographic categories are largely self-reported, as they are identified to hospital staff, and the researcher had no contact with the living individuals. In reference to the skeletal remains, the demographic categories have been largely assessed by collection personnel; however, if unknowns do exist then they were assessed with standard aging and sexing techniques, if possible. If sex, age or ancestry could not be determined, then they were labeled as unknown in that category and they were not reported.

Secondly, fracture features (e.g. type), and fracture location (i.e. bone, side, specific location) were assessed via macroscopic examination of skeletal material. These data allowed a further elucidation of what kinds of injuries occur from different causes, as well as what areas of the bone may be more susceptible to accidental or intentional injuries. A standard worksheet was created to assess these features (see Appendix A) and was used to assess each of these criteria, which were then entered into an Excel spreadsheet for statistical analyses to be performed. The scoring criteria were adapted from Kimmerle and Baraybar (2008), as it is developed for skeletal collections with traumatic lesions. Measurements, if taken, were made with a standard, digital sliding caliper, and bony land marks were used to assess specific locations of fractures. For example, measurements of the ribs were made from the sternal end and fracture locations were related back to the original landmark.

Thirdly, injury features were recorded for each individual, such as mechanism of injury (if known from hospital or collection records), timing of injury (ante- or peri-mortem in general, and first, second, etc. for multiple injuries in a single bone, if sequence can be determined), and healing stage (0- no bone proliferation, 1- slight bone proliferation, 2- open fracture with important bone proliferation, and 3-healed fracture with callus formation and/or remodeling). The assessment of injury features were made according to Kimmerle and Baraybar (2008) via macroscopic examination of skeletal material and radiographs. These data allowed for injuries that occurred during life to be separated from those incurred during death, as well as provided a sequence of events in some instances with multiple traumas, and to distinguish known accidents from intentional trauma. Lastly, these data categories were analyzed with respect to one another in order to identify any patterns between demographics, fracture types, and injury features.

## Analysis

The data generated from these analyses were analyzed with the statistical package SPSS 23 for which access is granted by the University of Tennessee (see File 1 for raw data). Two spreadsheets were generated. The first spreadsheet includes a list of each individual along with their demographics, cause of death, region of injury, and a listing of body areas and the presence (1) or absence (0) of a fracture. The second spreadsheet includes individual injuries, as some individuals had more than one bone affected, and some even had more than one injury event with separate timings of injuries. SPSS was chosen for the user-friendly interface and the ease of importing data, specifically for categorical analyses involving cross-tabulations, chi-squares, and logistic regression.

In order to discern if there is a unique pattern of injury to accidental and intentional trauma, these data employed chi-square analyses using SPSS. Cross-tabulations were made using SPSS to identify if this pattern varies by any of the demographic categories. An estimated value is generated based on the data for what would be expected if no difference existed between two groups (e.g. femoral neck fractures in males vs. females). Any deviations in the cross-tabulations are assessed against a chi-square value and are found to be significantly different or not against an alpha value of 0.05 (SPSS 23). Therefore, if women have observed counts that are higher than the generated expected counts for femoral fractures in the sample, and this difference is significantly different, then women have sustained more femoral fractures than statistically expected. This could be evidence for a predisposition in this group, but other characteristics are likely to be assessed as well.

Statistical significance within the cross-tabulations will be assessed by looking at the adjusted standardized residuals. For smaller samples, an adjusted residual of absolute value greater than 2.0 is an indication that this cell is driving some portion of the statistically significant differences. For larger samples, an absolute value of 3.0 is used (Agresti 2007; Stoltzfus 2011). As the current sample is fairly large for an anthropological dataset with 227 individuals and 857 injuries, but small when compared to econometrics and other fields, a value of 2.0 was used to assess significant differences among cells in the cross-tabulations.

Logistic regression was also used to create a predictive model for accidental versus intentional injury types. Logistic regression was chosen as the response variable is binary and categorical (i.e. accidental=0 and intentional =1). The assumptions of normality, which are violated with categorical variables, are not a problem for this type of regression. Therefore, this analysis is particularly well suited to this type of data set as there are a number of categorical factors (e.g. fracture type), but only one scale variable (age). Model selection occurred simultaneously with running the regression procedure and utilized a forward stepwise selection procedure based on the Wald test. This is a test that is based off of the chi-square distribution, which makes it applicable to categorical data. The goodness of fit test that will be used is the Hosmer-Lemeshow Test, which is an accepted test for model fit in logistic regression (Agresti 2007; SPSS 2015; Stoltzfus 2011).

Unlike linear regression, logistic regression doesn't generate a true R square, though there are pseudo R square tests that can have similar, though not exact interpretations. This study utilized Cox and Snell and Nagelkerke R square calculations for the logistic regression procedure and those are presented with the results. As the pseudo R square is not a true R square, the values tend to be lower and reported less in the literature. Therefore, a low pseudo R

square does not necessarily indicate that the model is not functioning properly, as one expects with linear regression. Logistic regression is, however, one of the best procedures for modelling categorical variables (Agresti 2007; SPSS 2015; Stoltzfus 2011).

Intra-observer error was calculated on three passes of 30 individuals from the dataset. The Kappa statistic was used to assess intra-observer reliability, as it is appropriate for nominal and ordinal data. Fleiss' kappa was used as there were more than two passes of the data that were analyzed. This is a generalization of Cohen's kappa that allows for a contingency table that is greater than 2x2. A kappa value of 0.41-0.60 is considered moderate strength of agreement. A value of 0.61-0.80 is considered a substantial strength of agreement. Lastly, a kappa of 0.81-1.00 reflects a strength of agreement that is considered almost perfect (Fleiss 1971).

The data generated from these analyses included demographic information for each individual (i.e. age, sex, ancestry, cause of death) and injury information (cause, location, frequency, characteristics). The data were gathered and handled by the author, who was the sole individual to gather the data. Data comprised only written data (from examinations of skeletal material) that were then entered into a personal computer. All data were stored on password protected computers and all identifying information for individuals was unknown to the author and was not included in any databases or spreadsheets.

## **Chapter 6: Results**

### **Regional chi-square analyses**

Chi-square tests were run on the regional data to see if there were any statistically significant differences between the observed and expected values for sex and ancestry, as they compared to accidental and intentional injuries, cause of death, region of injury, body area, and side of injury. The alpha was set for all tests at 0.05. There was one statistically significant difference seen in the data by sex (see Table 2). This concerned the lower leg and shows that males had fewer lower leg fractures than expected, whereas females had a higher number of lower leg fractures than expected (see Table 3). This suggests that the sexes can possibly be pooled for further analyses.

The chi-square analyses for ancestry show that there are no significant differences among ancestry groups for all factors, except for side (see Table 4). The adjusted residuals for side (see Table 5) show that unknown side of injury is more frequently found in black and hispanic groups than expected. In contrast, the white group has fewer fractures of unknown side than expected. These injuries were largely comprised of segments of crania with ballistic trauma from the Regional Forensic Center.

Chi-square analyses were also run on accidental versus intentional injuries in reference to sex, ancestry, cause of death, region, body area, and side (see Table 6). There were no significant differences with respect to sex, ancestry, side, neck, hand, and foot. There were significant differences for cause of death, region, lower leg, thigh, forearm, upper arm, trunk, and head. There were fewer instances than expected for the accidental group in relation to sharp

**Table 2. Cross-tabulations by sex n=204.**

<b>Factor</b>	<b>Chi-squared Value</b>	<b>P- Value</b>
Cause of death	14.598	0.160
Accident/Intentional	1.246	0.173
Region	2.402	0.509
Side	4.051	0.377
Head	2.364	0.086
Neck	2.849	0.281
Trunk	0.056	0.470
Upper arm	0.053	0.587
Forearm	1.328	0.226
Hand	1.042	0.412
Thigh	0.237	0.401
<b>Lower leg</b>	<b>5.491</b>	<b>0.025*</b>
Foot	0.639	0.446

**Table 3. Cross-tabulations for sex by lower leg.**

<b>Lower Leg</b>	<b>Sex</b>	<b>Adjusted residual</b>
Absent	Male	2.3
Present	Male	-2.3
Absent	Female	-2.3
Present	Female	2.3

**Table 4. Cross-tabulations by ancestry (n=202).**

<b>Factor</b>	<b>Chi-squared Value</b>	<b>P- Value</b>
Cause of death	17.987	0.711
Accident/Intentional	3.069	0.209
Region	4.461	0.539
<b>Side</b>	<b>15.182</b>	<b>0.033*</b>
Head	0.874	0.760
Neck	2.947	1.000
Trunk	0.380	0.929
Upper arm	0.356	1.000
Forearm	0.410	1.000
Hand	5.570	0.105
Thigh	0.356	0.834
Lower leg	0.859	0.765
Foot	1.555	1.000

**Table 5. Cross-tabulations for ancestry by side.**

<b>Side Group</b>	<b>Ancestry</b>	<b>Adjusted Residual</b>
Unknown	White	-4.0
Unknown	Black	2.1
Unknown	Hispanic	3.9

**Table 6. Cross-tabulations for accidental/intentional injury (n=210).**

<b>Factor</b>	<b>Chi-Squared Value</b>	<b>P-Value</b>
<b>Head</b>	<b>21.679</b>	<b>0.000*</b>
Neck	2.744	0.132
<b>Trunk</b>	<b>30.205</b>	<b>0.000*</b>
<b>Upper arm</b>	<b>10.221</b>	<b>0.004*</b>
<b>Forearm</b>	<b>8.000</b>	<b>0.009*</b>
Hand	0.016	1.000
<b>Thigh</b>	<b>21.316</b>	<b>0.000*</b>
<b>Lower leg</b>	<b>27.268</b>	<b>0.000*</b>
Foot	4.712	0.089
<b>Region</b>	<b>65.110</b>	<b>0.000*</b>
<b>Cause of Death</b>	<b>179.036</b>	<b>0.000*</b>
Ancestry	3.159	0.374
Sex	1.633	0.479
Side	3.561	0.462

force trauma, blunt force trauma (known weapon), and gunshot wounds. There were more instances than expected in the accidental group for motor vehicle accidents (both general and pedestrian), falls/trips/jumps, and unknown causes of death. There were fewer instances than expected for the intentional group with respect to motor vehicle accidents of both types, falls/trips/jumps and unknown causes of death. There were more instances than expected for the intentional group as concerns gunshot wounds, blunt force trauma (known weapon), and sharp force injuries (see Table 7). As concerns the analysis for region (see Table 8), the accidental group had more instances than expected for the category that included multiple affected regions, and the limbs, and fewer than expected injuries for the head and neck. The intentional group had fewer than expected instances of trauma for the multiple region category and the limbs, and more than expected for the head and neck (see Table 8).

Chi-square analyses for body areas show that the accidental group had fewer instances of head trauma than expected, whereas the intentional group had more instances of head trauma than expected (see Table 9). The trunk, upper arm, forearm, thigh, and lower leg all had more accidental injuries than expected and fewer intentional injuries than expected (see Tables 10, 11, 12, 13, and 14). This shows a clear tendency for more accidental, appendicular injuries and more head-focused, intentional injuries.

### **Individual injury chi-square analyses**

Chi-square analyses were performed on the dataset with individual injuries listed. The first analyses were run by sex and ancestry and an alpha of 0.05 was used to determine statistical significance. In the analyses by sex, completeness of fracture, bone class, fracture type, and mechanism of injury were statistically significant (see Table 15). Males had more complete fractures and fewer incomplete and indeterminate fractures than expected (see Table 16).

**Table 7. Cross-tabulations for accidental/intentional injury by cause of death (n=210).**

<b>Cause of Death</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Gunshot Wound	Accidental	-6.4
Gunshot Wound	Intentional	6.4
Motor Vehicle Accident	Accidental	7.7
Motor Vehicle Accident	Intentional	-7.7
MVA Pedestrian	Accidental	5.9
MVA Pedestrian	Intentional	-5.9
Sharp Force Known Weapon	Accidental	-2.8
Sharp Force Known Weapon	Intentional	2.8
Blunt Force Known Weapon	Accidental	-2.1
Blunt Force Known Weapon	Intentional	2.1
Fall/Trip/Jump	Accidental	4.2
Fall/Trip/Jump	Intentional	-4.2
Unknown	Accidental	4.1
Unknown	Intentional	-4.1

**Table 8. Cross-tabulations for accidental/intentional injury by region (n=210).**

<b>Region</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Head and neck	Accidental	-7.4
Limbs	Accidental	4.1
Multiple	Accidental	5.6
Head and neck	Intentional	7.4
Limbs	Intentional	-4.1
Multiple	Intentional	-5.6

**Table 9. Cross-tabulations for accidental/intentional injury by head (n=210).**

<b>Head</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Present	Accidental	-4.7
Absent	Accidental	4.7
Present	Intentional	4.7
Absent	Intentional	-4.7

**Table 10. Cross-tabulations for accidental/intentional injury by trunk (n=210).**

<b>Trunk</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Present	Accidental	5.5
Absent	Accidental	-5.5
Present	Intentional	-5.5
Absent	Intentional	5.5

**Table 11. Cross-tabulations for accidental/intentional injury by upper arm (n=210).**

<b>Upper Arm</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Present	Accidental	3.3
Absent	Accidental	-3.2
Present	Intentional	-3.2
Absent	Intentional	3.2

**Table 12. Cross-tabulations for accidental/intentional injury by forearm (n=210).**

<b>Forearm</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Present	Accidental	2.8
Absent	Accidental	-2.8
Present	Intentional	-2.8
Absent	Intentional	2.8

**Table 13. Cross-tabulations for accidental/intentional injury by thigh (n=210).**

<b>Thigh</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Present	Accidental	4.6
Absent	Accidental	-4.6
Present	Intentional	-4.6
Absent	Intentional	4.6

**Table 14. Cross-tabulations for accidental/intentional injury by lower leg (n=210).**

<b>Lower Leg</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Present	Accidental	5.2
Absent	Accidental	-5.2
Present	Intentional	-5.2
Absent	Intentional	5.2

**Table 15. Cross-tabulations by sex (n=857).**

<b>Factor</b>	<b>Chi-Square Value</b>	<b>P-Value</b>
<b>Completeness</b>	<b>23.814</b>	<b>0.000*</b>
<b>Bone Class</b>	<b>21.803</b>	<b>0.016*</b>
<b>Fracture Type</b>	<b>89.108</b>	<b>0.000*</b>
Side	9.551	0.267
<b>Mechanism of Injury</b>	<b>45.931</b>	<b>0.000*</b>
Timing of Injury	6.970	0.109

**Table 16. Cross-tabulations for completeness of fracture by sex (n=857).**

<b>Completeness</b>	<b>Sex</b>	<b>Adjusted Residual</b>
Complete	Male	4.1
Incomplete	Male	-3.2
Indeterminate	Male	-2.7
Complete	Female	-4.7
Incomplete	Female	3.8
Indeterminate	Female	2.6

Conversely, females had fewer complete fractures, and more incomplete and indeterminate fractures than expected (see Table 16). Females also had fewer injuries to the flat bones of the Body (see Table 17). As concerns the fracture type, males had more comminuted fractures, and fewer crush, depressed, and keyhole fractures than expected (see Table 18). Females had fewer comminuted fractures, but more crush, depressed, and simple linear fractures than expected (see Table 18). Individuals of unknown sex had more circular and keyhole defects, but fewer simple linear fractures than expected (see Table 18). Lastly, females had more blunt force, unknown, and combination of mechanisms of injury, and fewer ballistic injuries than expected (see Table 19). Males had more ballistic injuries than expected (see Table 19). Individuals of indeterminate sex had fewer blunt force and more ballistic injuries than expected (see Table 19).

Chi-square analyses by ancestry show that there are statistically significant differences among ancestry groups in all variables, except completeness of fracture (see Table 20). For bone class, white individuals have fewer flat bones affected and more irregular bone affected by trauma than expected. Hispanic individuals have more flat bones affected by trauma, and also more bones of indeterminate class affected than expected (see Table 21). White individuals have fewer fractures than expected for the following fracture types: circular, cut mark, keyhole, puncture, and unknown (see Table 22). Black individuals have more keyhole fractures than expected (see Table 22). Hispanic individuals have more cut mark and unknown fracture types than expected (see Table 22). Individuals of unknown ancestry have more fractures than expected for circular, keyhole, and puncture trauma types, and fewer instances than expected for simple linear fractures (see Table 22). The side of the injury analysis shows that white individuals have fewer injuries of unknown side; whereas hispanic individuals have more injuries of unknown side (see Table 23). The mechanism of injury also differed among ancestry

**Table 17. Cross-tabulations for bone class by sex (n=857).**

<b>Bone Class</b>	<b>Sex</b>	<b>Adjusted Residual</b>
Flat	Female	-2.4
Flat	Unknown	2.4

**Table 18. Cross-tabulations for fracture type by sex (n=857).**

<b>Fracture Type</b>	<b>Sex</b>	<b>Adjusted Residual</b>
Circular	Unknown	5.8
Comminuted	Male	3.5
Comminuted	Female	-3.2
Crush	Male	-2.3
Crush	Female	2.0
Depressed	Male	-3.7
Depressed	Female	4.0
Keyhole	Male	-2.1
Keyhole	Unknown	2.9
Simple Linear	Female	2.3
Simple Linear	Unknown	-2.3
Unknown	Unknown	2.1

**Table 19. Cross-tabulations for mechanism of injury by sex (n=857).**

<b>Mechanism</b>	<b>Sex</b>	<b>Adjusted Residual</b>
Blunt Force	Female	3.4
Blunt Force	Unknown	-3.9
Ballistic	Male	2.6
Ballistic	Female	-4.4
Ballistic	Unknown	4.8
Unknown	Female	2.1
Combination	Female	2.0

**Table 20. Cross-tabulations for ancestry (n=857).**

<b>Factor</b>	<b>Chi-Square Value</b>	<b>P-Value</b>
Completeness	11.083	0.058
<b>Bone Class</b>	<b>29.930</b>	<b>0.026*</b>
<b>Fracture Type</b>	<b>116.477</b>	<b>0.000*</b>
<b>Side</b>	<b>26.441</b>	<b>0.009*</b>
<b>Mechanism of Injury</b>	<b>43.348</b>	<b>0.000*</b>
<b>Timing of Injury</b>	<b>14.337</b>	<b>0.019*</b>

**Table 21. Cross-tabulations for bone class by ancestry (n=857).**

<b>Bone Class</b>	<b>Ancestry</b>	<b>Adjusted Residual</b>
Flat	White	-2.9
Flat	Hispanic	2.3
Irregular	White	3.1
Unknown	Hispanic	2.8
Unknown	Unknown	2.1

**Table 22. Cross-tabulations for fracture type by ancestry (n=857).**

<b>Fracture Type</b>	<b>Ancestry</b>	<b>Adjusted Residual</b>
Circular	White	-3.9
Circular	Unknown	4.2
Cut Mark	White	-2.7
Cut Mark	Hispanic	2.4
Keyhole	White	-4.1
Keyhole	Black	3.7
Keyhole	Unknown	2.6
Simple Linear	Unknown	-2.0
Puncture	White	-3.3
Puncture	Unknown	6.5
Unknown	White	-2.9
Unknown	Hispanic	2.6

**Table 23. Cross-tabulations for side by ancestry (n=857).**

<b>Side</b>	<b>Ancestry</b>	<b>Adjusted Residual</b>
Unknown	White	-2.9
Unknown	Hispanic	2.6

groups. White individuals had fewer instances of an unknown mechanism, while black individuals had more unknown mechanism than expected (see Table 24). Hispanic individuals had more sharp force and unknown mechanisms of injury than expected (see Table 24). Individuals of unknown ancestry had fewer blunt force injuries, and more ballistic injuries, than expected (see Table 24). Lastly, there were also differences in the timing of injuries. White individuals had more antemortem injuries, and fewer unknown injuries than expected (see Table 25). Hispanic and individuals of unknown ancestry had more unknown timings than expected (see Table 25).

All chi-square analyses were statistically significant for accidental and intentional injuries by complete versus incomplete fractures, bone class, fracture type, bone, mechanism of injury, and timing of injury (see Table 26).. For complete/incomplete fractures, there are fewer incomplete fractures in the accidental group than expected and more incomplete fractures in the intentional group than expected (see Table 27). In addition, the unknown category has a count greater than expected for the accidental group and fewer examples than expected for the intentional group (see Table 27).

The chi-square analyses for accidental versus intentional injury by bone were statistically significant (see Table 28) and show that there are more accidental injuries than expected and fewer intentional injuries than expected for the ribs, femur, fibula, humerus, os coxa, nasals, radius, and tibia. The opposite pattern is true for the temporals, parietals, occipital, hyoid, and frontal (see Table 28).

The chi-square analyses for bone class also show a statistically significant difference between the accidental and intentional group (see Table 29). There are fewer fractures to flat bones than expected for the accidental group and there are more fractures than expected for the

**Table 24. Cross-tabulations for mechanism of injury by ancestry (n=857).**

<b>Mechanism</b>	<b>Ancestry</b>	<b>Adjusted Residual</b>
Blunt Force	Unknown	-3.5
Ballistic	Unknown	3.4
Sharp Force	Hispanic	3.3
Unknown	White	-4.2
Unknown	Black	4.4
Unknown	Hispanic	2.6

**Table 25. Cross-tabulations for timing of injury by ancestry (n=857).**

<b>Timing</b>	<b>Ancestry</b>	<b>Adjusted Residual</b>
Antemortem	White	2.1
Unknown	White	-3.2
Unknown	Hispanic	2.8
Unknown	Unknown	2.1

**Table 26. Cross-tabulations by accidental/intentional injuries (n=857).**

<b>Factor</b>	<b>Chi-Square Value</b>	<b>P-Value</b>
<b>Completeness</b>	<b>11.976</b>	<b>0.002*</b>
<b>Bone</b>	<b>245.489</b>	<b>0.000*</b>
<b>Bone Class</b>	<b>104.194</b>	<b>0.000*</b>
<b>Fracture Type</b>	<b>183.464</b>	<b>0.000*</b>
<b>Side</b>	<b>39.363</b>	<b>0.000*</b>
<b>Mechanism of Injury</b>	<b>382.971</b>	<b>0.000*</b>
<b>Timing of Injury</b>	<b>83.409</b>	<b>0.000*</b>

**Table 27. Cross-tabulations for completeness by accidental/intentional injuries (n=857).**

<b>Completeness</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Incomplete	Accidental	-2.4
Incomplete	Intentional	2.4
Unknown	Accidental	2.8
Unknown	Intentional	-2.8

**Table 28. Cross-tabulations for bone by accidental/intentional injuries (n=857).**

<b>Bone</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Femur	Accidental	4.2
Femur	Intentional	-4.2
Fibula	Accidental	5.3
Fibula	Intentional	-5.3
Frontal	Accidental	-3.4
Frontal	Intentional	3.4
Humerus	Accidental	2.5
Humerus	Intentional	-2.5
Hyoid	Accidental	-2.4
Hyoid	Intentional	2.4
Os coxa	Accidental	4.5
Os coxa	Intentional	-4.5
Nasals	Accidental	3.2
Nasals	Intentional	-3.2
Occipital	Accidental	-2.9
Occipital	Intentional	2.9
Parietal	Accidental	-5.5
Parietal	Intentional	5.5
Radius	Accidental	2.8
Radius	Intentional	-2.8
Ribs	Accidental	4.7

**Table 28. Continued.**

<b>Bone</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Ribs	Intentional	-4.7
Temporal	Accidental	-4.2
Temporal	Intentional	4.2
Tibia	Accidental	5.0
Tibia	Intentional	-5.0

**Table 29. Cross-tabulations for bone class by accidental/intentional injuries (n=857).**

<b>Bone Class</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Flat	Accidental	-6.7
Flat	Intentional	6.7
Long	Accidental	10.0
Long	Intentional	-10.0

intentional group. There are also more long bone fractures than expected for the accidental group and fewer long bone fractures than expected for the intentional group (see Table 29).

The chi-square analysis for accidental and intentional injuries by fracture type was also statistically significant (see Table 30). There were more comminuted fractures than expected in the accidental group, with fewer than expected in the intentional group. The same pattern is true, with more accidental fractures than expected and fewer intentional fractures than expected, for crush, simple linear, comminuted, and segmental fractures. The opposite pattern, fewer fractures than expected for the accidental group and more than expected for the intentional group, is seen in circular, cut mark, combination, and radiating fractures (see Table 30).

Chi-square analyses by side were also significant and showed that there were more right-sided accidental injuries, and fewer right-sided intentional injuries (see Table 31). In addition, fractures that affected unpaired bones, or affected the midline were more numerous in the intentional category and less numerous in the accidental category than expected (see Table 31).

The chi-square analyses for accidental versus intentional injury by mechanism of injury were statistically significant (see Table 32) and show that there were fewer than expected ballistic and sharp force injuries within the accident group. There were also more blunt force trauma injuries for the accident group than was expected (see Table 32). Conversely, the intentional group experienced fewer blunt force injuries, and more ballistic and sharp force injuries than expected (see Table 32).

The chi-square analyses for accidental and intentional injuries by timing of the injury were also statistically significant (see Table 33) and show that there were more antemortem accidental injuries than expected, with fewer antemortem intentional injuries. In contrast, there

**Table 30. Cross-tabulations for fracture type by accidental/intentional injuries (n=857).**

<b>Fracture Type</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Combination	Accidental	-2.0
Combination	Intentional	2.0
Circular	Accidental	-5.5
Circular	Intentional	5.5
Comminuted	Accidental	4.0
Comminuted	Intentional	-4.0
Crush	Accidental	5.6
Crush	Intentional	-5.6
Cut Mark	Accidental	-2.1
Cut Mark	Intentional	2.1
Simple Linear	Accidental	7.2
Simple Linear	Intentional	-7.2
Radiating	Accidental	-7.7
Radiating	Intentional	7.7
Segmental	Accidental	4.3
Segmental	Intentional	-4.3

**Table 31. Cross-tabulations for side by accidental/intentional injuries (n=857).**

<b>Side</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Right	Accidental	4.2
Right	Intentional	-4.2
Unsided/Midline	Accidental	-5.7
Unsided/Midline	Intentional	5.7

**Table 32. Cross-tabulations for mechanism of injury by accidental/intentional injuries (n=857).**

<b>Mechanism</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Blunt Force	Accidental	17.0
Blunt Force	Intentional	-17.0
Ballistic	Accidental	-14.7
Ballistic	Intentional	14.7
Sharp Force	Accidental	-5.7
Sharp Force	Intentional	5.7

**Table 33. Cross-tabulations for timing of injury by accidental/intentional injuries (n=857).**

<b>Timing</b>	<b>Cause</b>	<b>Adjusted Residual</b>
Antemortem	Accidental	9.4
Antemortem	Intentional	-9.4
Perimortem	Accidental	-8.6
Perimortem	Intentional	8.6

were fewer perimortem accidental injuries, and more intentional perimortem injuries than expected (see Table 33).

## **Logistic Regression**

Logistic regression analyses were run on the dataset by region, body areas, and individual injuries, in order to see if there is a predictable model that fits the data adequately. Only significant variables from the chi-squared analyses of accidental and intentional injuries were retained as variables. The first analysis models accidental/intentional trauma based on age, ancestry, sex, complete/incomplete fracture, bone class, and fracture type. The variables cause of death, mechanism of injury, and timing of injury were not included as these may not be known, or difficult to determine, in an unknown case. In addition, bone was removed from the analysis as bone and bone class was likely to model the same information. As bone class had fewer levels, and would provide a more stream-lined interpretation, it was retained for the logistic regression analyses. A forward stepwise (Wald) selection procedure was used and age, ancestry, completeness, bone class and fracture type were retained in the model (see Table 34). The Model summary shows the Nagelkerke R square as 0.422 for the model and Cox and Snell is 0.304, which means that the variance in the response variable is fairly well predicted by the predictors/factors in the model. The Hosmer-Lemeshow Goodness of Fit test is 0.959, so there doesn't appear to be a problem with the model. The classification table (see Table 35) shows that 52.1% of accidental and 89.8% of intentional injuries are predicted to be in the correct category by the model. The overall correct classification rate is 77.2%.

Logistic regression analyses were also run on the dataset that included regional data by individual. The first analysis was run on accidental versus intentional injuries by age, sex,

**Table 34. Variables entered into the regression model by individual injuries.**

Variable	B	S.E.	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
							Lower	Upper
Age	-.027	.006	22.377	1	.000	.974	.963	.984
Ancestry			10.127	3	.018			
Ancestry (1)	18.412	12277.787	.000	1	.999	99146993.991	.000	.
Ancestry (2)	18.802	12277.787	.000	1	.999	146429313.615	.000	.
Ancestry (3)	16.016	12277.787	.000	1	.999	9032735.904	.000	.
Completeness			17.020	2	.000			
C/I(1)	.798	.557	2.051	1	.152	2.222	.745	6.624
C/I(2)	1.824	.597	9.343	1	.002	6.196	1.924	19.953
Bone Class			35.757	5	.000			
Bone Class(1)	-23.946	14539.673	.000	1	.999	.000	.000	.
Bone Class(2)	-3.630	31247.703	.000	1	1.000	.027	.000	.
Bone Class (3)	-24.064	14539.673	.000	1	.999	.000	.000	.
Bone Class (4)	-25.627	14539.673	.000	1	.999	.000	.000	.
Bone Class (5)	-2.308	31923.964	.000	1	1.000	.099	.000	.
Fracture Type			67.031	12	.000			
Type(1)	3.767	1.318	8.165	1	.004	43.230	3.264	572.494
Type (2)	-21.489	40192.970	.000	1	1.000	.000	.000	.

**Table 34. Continued.**

Variable	B	S.E.	Wald	df	Sig.	Exp(B)	Confidence Interval	
							Lower	Upper
Type (3)	22.984	5667.861	.000	1	.997	959197751 8.020	.000	.
Type (4)	2.441	1.265	3.723	1	.054	11.481	.962	137.0 01
Type (5)	-1.262	1.630	.599	1	.439	.283	.012	6.913
Type (6)	38.756	17700.515	.000	1	.998	678242245 28678000.0 00	.000	.
Type (7)	3.500	1.646	4.522	1	.033	33.119	1.315	833.9 13
Type (8)	22.894	19112.137	.000	1	.999	876576835 7.832	.000	.
Type (9)	1.619	1.254	1.666	1	.197	5.047	.432	58.94 9
Type (10)	40.145	42026.407	.000	1	.999	272056908 896951712. 000	.000	.
Type (11)	3.188	1.259	6.412	1	.011	24.240	2.055	285.9 09
Type (12)	-18.043	12847.524	.000	1	.999	.000	.000	.
Constant	4.344	19030.120	.000	1	1.00 0	77.052		

**Table 35. Classification table for logistic regression by individual injuries.**

<b>Observed</b>	<b>Predicted</b>		<b>Correct</b>
	<i>Accidental</i>	<i>Intentional</i>	
<i>Accidental</i>	139	128	52.1
<i>Intentional</i>	54	476	89.8
<b>Overall Percentage</b>			77.2

ancestry, and region. Cause of death and side were excluded from the model as they are not likely to be known (cause of death), and did not give much information (side) in the chi-square analyses. The variables that were retained in the model were age and region (see Table 36). The Cox and Snell R square is 0.316 and Nagelkerke is 0.442, which show that the predictors do a reasonably good job of predicting the variance in the response variable. The Hosmer-Lemeshow test has a value of 0.038, which is significant, but does not necessarily indicate that the model is functioning poorly, as this statistic tends to be overly conservative (Agresti 2007). The classification table also shows that accidental injuries are predicted correctly 70.5% of the time, with 90.8% for intentional injuries (see Table 37). This is a marked improvement over the classification rate of the previous model.

A final logistic regression analysis was run that includes age, sex, ancestry, and the individual body areas. The selected predictors/factors include age, trunk, thigh, and lower leg (see Table 38). The Hosmer-Lemeshow value is 0.386, which shows that the model is likely performing well. In addition, the Cox and Snell R square is 0.299 and the Nagelkerke R square is 0.419, which indicates that the selected variables are predicting the variance in the response variable reasonably well. The classification table (see Table 39) shows that 57.4% of accidental injuries are predicted correctly and 88.5% of intentional injuries are predicted correctly. The overall classification rate is 78.6%. This performs slightly better than the regression with region, but worse than the regression on individual injuries.

### **Intra-observer error**

Kappa statistics were calculated for fracture type, bone class, completeness, side, and region (see Table 40). The other variables were excluded from this analysis, as they were not

**Table 36. Variables entered into the regression model by region.**

Variable	B	S.E.	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
							Lower	Upper
age	-.036	.012	9.183	1	.002	.965	.943	.987
Region			47.295	3	.000			
Region(1)	3.144	.523	36.072	1	.000	23.198	8.315	64.721
Region(2)	1.250	.541	5.338	1	.021	3.489	1.209	10.071
Region(3)	-.458	.785	.340	1	.560	.633	.136	2.949
Constant	.773	.676	1.307	1	.253	2.167		

**Table 37. Classification table for logistic regression by region.**

<b>Observed</b>	<b>Predicted</b>		<b>Correct</b>
	<i>Accidental</i>	<i>Intentional</i>	
<i>Accidental</i>	43	18	70.5
<i>Intentional</i>	12	119	90.8
<b>Overall Percentage</b>			84.4

**Table 38. Variables entered into the regression model by body area.**

Variable	B	S.E.	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
							Lower	Upper
Age	-.039	.012	11.163	1	.001	.962	.940	.984
Trunk	-1.942	.404	23.143	1	.000	.143	.065	.316
Thigh	-1.251	.642	3.800	1	.051	.286	.081	1.007
Lower Leg	-3.604	.905	15.849	1	.000	.027	.005	.160
Constant	3.843	.700	30.095		.000	46.646		

**Table 39. Classification table for logistic regression by body area.**

<b>Observed</b>	<b>Predicted</b>		<b>Correct</b>
	<i>Accidental</i>	<i>Intentional</i>	
<i>Accidental</i>	35	26	57.4
<i>Intentional</i>	15	116	88.5
<b>Overall Percentage</b>			78.6

**Table 40. Intra-observer kappa values for three trials n=30.**

<b>Factor</b>	<b>Kappa Value</b>
Fracture Type	0.929
Bone Class	0.942
Completeness	0.782
Side	0.898
Region	0.939

assigned by the observer and were given via medical records, case reports, or curation records. Fracture type, bone class, side and region had an almost perfect strength of agreement among the three passes. This is determined as a kappa value from 0.81-1.00. Completeness had a kappa value that fell in the substantial strength of agreement category (0.61-0.80). Therefore, the reliability of the predictors/factors in this analysis is strong.

## **Chapter 7: Discussion**

### **Chi-square analyses by sex**

The regional dataset had only one significant difference between the sexes. There were more lower leg injuries than expected for females and fewer injuries than expected for males. The lower leg is often injured in motor vehicle versus pedestrian injuries and it would be interesting to see if females were more likely to be the victims of such accidents (Galloway 1999). The data present in the current study does not highlight a difference in the sexes between this type of injury, however it may be suggestive of different environmental factors that may predispose females to this type of trauma, such as fragility fractures due to osteoporosis or nutritional differentials based on socioeconomic status. As the lower leg is a load bearing region, any susceptibility to fracture in this area could have substantial consequences for the mobility of the individual who suffers an injury to this region.

The individual injury dataset revealed differences in completeness, bone class, fracture type, and mechanism of injury. As males had a higher number of complete fractures than expected, it could be surmised that the injuries that they are sustaining are happening at a higher force than their female counterparts, who experienced more incomplete fractures. Many studies of emergency room trauma victims indicate that males tend to present to hospitals with more traumatic injuries than their female counterparts (Breiting et al. 1989; Elliot Brown et al. 1998). This may be due to the fact that there is a propensity for greater risk-taking behavior in young men, as well as socialization toward violence in some groups of males (Walker 2001). Conversely, many studies have shown that victims of interpersonal violence, especially female victims, do not often present to medical facilities. Therefore, the true nature of the direct

violence toward female groups may be unknown. There is often a stigma associated with this kind of violence and an effort is made on the part of the victim to hide the injuries, so the true numbers of trauma may be largely unknown (Sheridan and Nash 2007).

This observation ties into that fact that females tend to experience more blunt force trauma than expected, with less ballistic trauma than expected. As most instances of interpersonal violence are executed with a fist, or found household objects, the fact that there is more blunt force trauma among women may not be all that surprising (Sheridan and Nash 2007). There may be a higher tendency for males to use firearms, which could explain their higher rates of ballistic trauma than expected. This may also explain why certain areas of the body are targeted differently by sex.

Males have more trauma to flat bones of the body than expected, and women have fewer than expected. The flat bones that were analyzed in this study are principally the bones of the skull. This shows a potential tendency for more cranial trauma among males. As the cranium is a particularly vulnerable area of the body, as it houses the brain, the fact that men experience more ballistic trauma may highlight the fact that there are more instances of ballistic, cranial injuries among individuals of this sex. This type of direct trauma is often intentional and may indicate a predisposition for this type of injury among males. Emergency room victims are often seen due to ballistic injuries in the United States (Breiting et al. 1989; Elliot Brown et al. 1998). This differs from other countries, such as the United Kingdom, where gun laws are more conservative. This also differs from areas, such as South America, where other weapons (e.g. machetes) may be more easily obtained than firearms.

## **Chi-square analyses by ancestry**

The regional analyses show that there are only significant differences between the ancestry groups as pertains to side. The white group has fewer instances of unknown sidings for trauma, and the black and hispanic groups have more instances of unknown trauma. This could be due to the comminution of certain wounds that make siding individual fragments difficult. In many ballistics injuries involving a high caliber weapon, for example, the resulting injury will heavily fragment the skull and make the siding of isolated fragments more difficult. This could lead one to believe that white individuals may experience differences in the mechanism of injury, bone class, and fracture type if the sample size could be improved. As it stands, these findings are only suggestive of a link between ancestry and injury type.

Additionally, the analysis of the individual injury dataset may show differences in the mechanism of injury by ancestry group. Hispanic individuals have more sharp force injuries than expected and white individuals have fewer unknown mechanisms of injury than their black or hispanic counterparts. The larger number of sharp force injuries among hispanics is likely an artifact of small sample size, and a difference may not be significant if a larger number of individuals were incorporated into the study. The flat bones of the body are affected more than expected among the hispanic group and there are fewer injuries to these bones than expected for the white group. This again may show a preference for instances of deadly force, as the head is a particularly vulnerable area. Any conclusions of this type may be untenable; however, as there are far fewer hispanic individuals included in the study as compared to white individuals. White individuals also have fewer instances of trauma for fracture types that are associated with ballistic trauma (such as circular and keyhole defects). Hispanics have more cut mark trauma, which mirrors the higher numbers of sharp force trauma in this group. This may be linked to the

fact that these individuals are assaulted by strangers more often than acquaintances, as other studies have demonstrated a link between sharp force trauma and unknown assailants (Ambade and Godbole 2006). The current study does not have information on the relationship of victim to attacker, so this is only a potential suggestion, which requires more research. In addition, black individuals have more keyhole defects, often associated with ballistic trauma, than their white counterparts. A larger study would need to be conducted in order to establish any clear patterns between mechanism of injury, weapon type, and ancestry.

### **Chi-square analyses by accidental and intentional injury**

The chi-square analyses reveal several interesting trends in the data. The first concerns the relationship between the cause of death and whether it represented accidental or intentional injury. Gunshot wounds were more likely to be intentional, which is not surprising as the purpose of a gun is to inflict damage with the fired projectile. It is also not surprising to find that there are more gunshot injuries in the intentional group, due to the nature of firearm use. Falls/trips/jumps were most often accidental; as falls and trips are unplanned this is also consistent with the literature (Tan and Porter 2006). Jumps can be difficult to differentiate from falls at all height levels, as they present similar injury patterns depending on the orientation of the body at impact (Guyomarc'h et al. 2009; Teh et al. 2003). Both types of motor vehicle accidents (general and pedestrian) were more numerous than expected for the accidental category. This is also consistent with the literature (Crandall et al. 2004). There have been occasions where a motor vehicle has been used to intentionally inflict damage or death, but in most instances these injuries result from accidents behind the wheel (Crandall et al. 2004). Sharp force trauma and ballistic trauma were more numerous than expected in the intentional

group. This again comes as no surprise as the intent of wielding a sharp edged, or ballistic, weapon is to inflict damage at impact. These are two of the most common intentional injury types, along with blunt force injuries (Galloway 1999; Kimmerle and Baraybar 2008). Overall, these trends match the literature and present no deviations from expectations. The patterning of injuries within the body also falls in line with the established literature.

The region, or body areas, that are affected vary by whether the cause was intentional or accidental. The head and neck were more frequently targets of intentional injuries than expected by the chi-squared analysis, which is consistent with the literature. Many studies (Bhandari et al. 2006; Crandall et al. 2004; Martin and Harrod 2015; Novak 1999; Petridou et al. 2002; Sheridan and Nash 2007; Wu 2010) cite the head and neck as the most commonly targeted sites of intentional or deliberate violence. The head is much less affected by accidental injury situations (Christensen 2004; Teh et al. 2003) and this data supports that conclusion. Ambade and Godbole (2006) found that blunt force trauma injuries disproportionately affect the head, whereas sharp force trauma is focused more on the thorax (chest). In addition, acquaintances were more likely to assault each other via blunt force, as opposed to unknown criminals who preferred sharp force trauma. In studies of intimate partner violence (IPV), the head and face were the primary targets in female victims for 62% of cases, and there was a similar tendency for head neck trauma in male victims (Petridou et al. 2002). The reasons behind why the face and neck are targeted are due to the vulnerability of the biological structures that underlie the skin. Some authors have also suggested that the facial injuries are an attempt to limit the social behavior of the victim, a desire for control, and to serve as a reminder of a power differential between the two individuals (Apel et al. 2011; Crandall et al. 2004; Novak 1999).

In contrast, the leg was more likely to be injured as a result of accidental trauma, which gives credence to the idea that intentional injury is more centrally focused (head, neck, and torso), whereas accidental injury is more widespread, distal and appendicular (Judd and Roberts 1998; Lyons et al. 2003; Martin and Harrod 2015). In fact, studies have shown that injuries to the extremities are not indicative of intentional violence (Wu 2010). For example, in falls there is a tendency for lower limb injuries, followed by the upper limb and head. Motor vehicle collisions also involve the lower limb most commonly, as well as the chest and upper limb (Crandall et al. 2004). Therefore, it is not surprising to find that this sample has a larger number of thigh injuries than expected, especially as it contains multiple motor vehicle collisions.

It is also interesting to note that there were more accidental cases of multiple injury sites affected than expected. Accidents have the capacity to affect multiple body areas, for example a fall down a flight of stairs (Iida et al. 2003; Teh et al. 2003). The face is an area that is frequently fractured in falls, as are other areas of the head, the spine, ribs, sternum, scapula, forearm and pelvis (The et al. 2003; Yamamoto 2010). Intentional injuries, however, can also affect multiple areas if a victim fights off an attacker, which can result in appendicular injuries, especially to the upper limb (Bhandari et al. 2006; Judd and Roberts 1998, 1999; O'Neill et al. 2001; Sheridan and Nash 2007; Wu 2010). The data in the present study, however, show that there was the potential for accidental injuries to affect more body areas than expected. The severity of the fracture also varied from group to group, which indicates that there may be differences in applied force.

There were more incomplete fractures in the intentional group than expected, and fewer in the accidental group than expected. This may be due to the fact that the accidental group contained 39 motor vehicle accidents, which generally occur at a higher velocity and may result

in fewer incomplete fractures. Fractures that were unknown, whether complete or incomplete, generally included antemortem fractures with significant remodeling that didn't allow for a clear categorization into either category. There were more of these fractures in the accidental than intentional group. This is potentially due to the fact that intentional trauma tends to be more focused and deliberate, as well as potentially more likely to result in the death of the individual, which wouldn't allow for significant remodeling to occur (Crandall et al. 2004; Sheridan and Nash 2007). The completeness of the fracture may also be related to the type of bone affected and its individual biomechanics.

Differences exist in the type of bone affected by each type of trauma. There were more flat bones affected by intentional trauma, for example. The flat bones affected in this sample comprise mainly the bones of the cranium. Gunshot trauma was more prevalent in the intentional group, and this is correlated with a high number of instances where the head was the primary target. Many studies have identified the head and neck as target areas of intentional violence (Bhandari et al. 2006; Crandall et al. 2004; Novak 1999; Petridou et al. 2002; Sheridan and Nash 2007; Wu 2010) and if an individual is looking to employ deadly force in the use of a hand gun, then the head is biologically a more vulnerable area to fire upon.

In contrast, there were more long bone injuries found in accidental trauma. The long bones of the arms and legs are particularly susceptible to accidental trauma from slips and falls, as well as an individual's attempts to right themselves during a fall or trip. This finding is in line with the established literature that claims accidental injuries are more distal, as well as more scattered throughout the body. The long bones of the arms and legs are likely areas of injury in these types of trauma (Christensen 2004; Guyomarc'h et al. 2010; Sanders et al. 2002; Tan and Porter 2006; Teh et al. 2003). The orientation of the body at impact is a leading determinant in

the areas that are injured. Individuals who land on their feet are more likely to experience pelvic and spinal injuries. This is especially true for jumpers, as they tend to land feet-first on more occasions than fallers. This is most likely due to the fact that they have more control over their starting position than someone experiencing a fall. In addition, rib fractures are also prevalent in falls and jumps. There has been a tendency for jumpers to present more right-sided rib fractures, whereas fallers have a more even distribution across both sides. Jumpers have also been found to have more right-sided forearm fractures, as compared to fallers (Christensen 2004; Teh et al. 2003). This highlights the importance of body positioning at the time of traumatic impact, as the position and location of an injury are affected by not only the surfaces they come into contact with, but also the regional variation in bone at an impact site. This variation has the ability to affect the types of fractures that may be present in the underlying bone.

The types of fractures that were prevalent among each group also varied in this study sample. There were more comminuted, crush, segmental, and simple linear fractures in the accidental group than expected according to the chi-square analysis. Comminuted fractures represent fractures that are broken into more than two segments and this is often resulting from high velocity forces (Kimmerle and Baraybar 2008). As the accidental group had many motor vehicle accidents, it is not surprising that they would experience more comminution at fracture sites. In addition, a fall onto an outstretched hand can also produce comminution at any of the arm joints if the arm is kept in a rigid or semi-rigid position at impact (Iida et al. 2003; Kimmerle and Baraybar 2008; Teh et al. 2003). Crush fractures can also result under similar loading conditions, as well as compression of the spine during a fall or motor vehicle accident. Segmental fractures are usually seen when a long bone breaks into 3 or more segments and as there were more long bone fractures among accidents, then it follows that there will be more

segmental fractures. Lastly, linear fractures can develop from a multitude of injury mechanisms and as falls, vehicle collisions, and other accidents tend to have varied causes with variable body position, it is likely that they will represent a variety of linear fractures (Galloway 1999; Hart 2005; Kimmerle and Baraybar 2008).

Among intentional injuries, there were more circular, cut mark, and radiating fractures. Cut marks are usually the result of sharp force trauma and represent a deliberate act of violence, so it is not surprising that they would be more numerous than expected in the intentional group (Apel et al. 2011; Kimmerle and Baraybar 2008; Sheridan and Nash 2007). As there is also a large number of ballistic injuries, especially to the cranium, the fact that there is more circular and radiating fractures is also not unexpected, as entry and exit defects have a tendency to be circular and are also associated with radiating fracture lines as the intracranial pressure disrupts the continuity of surrounding bone (Kimmerle and Baraybar 2008).

There were also a variety of bones found in the study that were affected either by accident or intentional violence more commonly. There were more fractures than expected for intentional trauma as concerns the ribs, fibula, humerus, os coxa, nasals, radius, and tibia. This somewhat breaks from the traditional head-neck-face model for intentional trauma, as the bones of the arm and trunk were fractured more than expected. The long bones of the arms and legs are often the site for accidental trauma, especially as these areas are often used to right the body and break falls and trips (Christensen 2004; Teh et al. 2003). The os coxa is also frequently affected in falls from a height and motor vehicle accidents, which fall under the accidental type of trauma (Christensen 2004; Crandall et al. 2004; Reber and Simmons 2015; Scalea et al. 1986). The long bones of the limbs can also be affected in cases of intentional trauma where the arms are used to defend against the attack (Bhandari et al. 2006; Byard et al. 2010; Crandall et al. 2004; Walker

2001). Therefore, the higher than expected number of humerus and radius injuries is not really a deviation from the literature, though some studies note that injuries of the upper limb are not a good predictor of intentional versus accidental trauma (Wu 2010). Additionally, the nasals are a thin and vulnerable set of bones, which are frequently injured in both accidental and intentional injuries. They can often be broken if the face impacts an object, such as a steering wheel or the floor (Sheridan and Nash 2007; Teh et al. 2003; Yamamoto 2010). These bones may not serve as a good predictor for differentiating accidental from intentional trauma along with the upper limb.

The intentional group saw more fractures than expected for the frontal, hyoid, and occipital. The head is often the target of blunt force injuries with and without a weapon, so the fact that the frontal and occipital are more numerous among intentional injuries is in agreement with the literature (Crandall et al. 2004; Novak 1999; Sheridan and Nash 2007; Wu 2010). In particular, face to face fights can result in damage to the frontal. The occipital is often exposed as well if an individual is knocked to the floor and a blow is struck to the back of the head (Sheridan and Nash 2007; Wu 2010). The hyoid fractures in this sample usually represent trauma associated with strangulation, where compression of the neck results in a fracture to one, or both, sides of the hyoid (Kimmerle and Baraybar 2008; Sheridan and Nash 2007). Though there can be accidental strangulations, this type of injury is generally employed more in instances of deliberate violence.

The mechanism of injury also varied among our groups in reference to the chi-square analyses. The accidental group had more instances of blunt force trauma than expected, with less ballistic and sharp force trauma. As motor vehicle accidents, falls, and trips, among other accidents, are usually the result of the body coming into contact with an object, or vice versa, the

resulting mechanism of injury is usually blunt force (Galloway 1999; Kimmerle and Baraybar 2008). In contrast, the intentional group had more ballistic and sharp force trauma. This is to be expected as a weapon is often employed in sharp force trauma with the intent to inflict damage. The same is true for the use of a firearm. The intent is to damage the target at impact, and when employed against another human being it is usually deliberately done (Kimmerle and Baraybar 2008). It should be noted, however, that there were many instances of blunt force trauma in the intentional group as well. There were instances of bludgeoning as a cause of death with instruments that varied from a hand, to baseball bats and fireplace pokers. Most objects employed in these cases appeared to be found objects that were near the assailant, which is common in blunt force assaults (Sheridan and Nash 2007).

The timing of injuries analysis also revealed results that were consistent with the literature. Accidental injuries had more antemortem injuries than expected. This is probably due to the collection of injuries throughout an individual's lifetime. Accidents can be varied and are not always high velocity. As such, there is a higher survival rate in a general accident, as compared to an instance of intentional trauma (Crandall et al. 2004; Guyomarc'h et al. 2010; Tan and Porter 2006). Conversely, intentional trauma had more cases of perimortem injury than expected. This could be because many assailants aim to kill the respective victim, so force is employed at a greater rate with a focus on vulnerable areas of the body, such as the head (Crandall et al. 2004; Kimmerle and Baraybar 2008).

## **Logistic regression**

The logistic regression analyses reveal some interesting findings as concerns the variables that are able to predict accidental versus intentional trauma. The best model run on all of the individuals' injuries highlighted ancestry, completeness of fracture, bone class, fracture type, and age as significant predictors of accidental or intentional group membership. The equation for this model will vary on the level an individual takes in each factor or predictor category. For example, the fracture type can be indicative of the type of trauma inflicted. For example, Guyomarc'h et al. (2010) found that falls produced more linear and radial fractures, whereas blows had more comminutions and depressed fractures. Other studies have noted that a direct impact may be more likely to result in a transverse fracture. In contrast, a direct force applied at some distance from the fracture site may result more frequently in an oblique fracture (Grauer and Roberts 1996). For example, an oblique fracture may develop in the tibia as a result of a fall from a low height. Cranial injuries are also more likely to display a depressed fracture than some other areas, such as long bones (Alvrus 1999). Conversely, ballistic trauma involves higher speed and produces generations of concentric fractures that may give researchers an idea of how fast this velocity may have been. Concentric fractures usually occur first on the outer table in blunt force trauma and at the inner table in ballistics. Therefore blunt force injuries can be identified by concentric fractures that are internally beveled, whereas ballistic concentric fractures will have an external bevel (Berryman and Haun 1996; Hart 2005).

The logistic regression for individual injuries was able to correctly classify individuals 77.2% of the time. This rate is good, but if the classification table is examined, one can see that the correct classification of accidents (52.1%) is only slightly better than chance. This model, therefore, does not do a reasonably good job of classifying this type of trauma. This may be due

in part to the fact that the variable for ancestry contains few non-white individuals and may not predict very much of the variation between accidental and intentional injuries. Analyses were also run on individual body areas and region to see if a better model exists.

The next logistic regression analysis was run on demographic categories, such as age, sex, and ancestry, as well as individual body areas. This model had age, trunk, thigh, and lower leg as significant predictors. As all of the coefficients for these predictors were negative, it shows that injuries to these areas are negatively correlated with intentional injury. The chi-square analyses also showed that these areas are more likely to be affected by accidental injury, as the literature claims. The overall classification rate was 78.6%, which is not poor in itself, but a closer inspection again reveals an issue with the classification of accidents. Accidents were classified with only 57.4% accuracy, which is little better than chance. This model performs slightly better than the individual injury model, but it is still not accurate enough to suggest likely implementation beyond this dataset. The ancestry variable and some of the body area variables are likely to have some small counts for certain categories (e.g. hispanic and black for ancestry), which may be the reason for poor model fit.

Lastly, logistic regression analyses were run on the model that had regional data and the model that was generated included the significant predictors: age and region. The negative coefficient for the variable age indicates that as age increases, the log-likelihood of an intentional injury decreases. This model classifies accidents correctly at 70.5%, intentional injuries at 90.8%, with an overall correct classification rate of 84.4%. This is a marked improvement over the preceding models. It also presents a much simpler regression equation:  $0.773 - 0.036(\text{age}) + 3.144 (\text{head/neck}) + 1.250(\text{trunk}) - 0.458(\text{limbs})$ . This model is the best predictor of

intentional/accidental injury of the three models assessed and provides evidence that further research into injury regions is likely to improve classification rates.

### **Limitations of the present study**

There are several limitations to the present study that concern the samples, variables, and statistics employed in the research. First, the number of individuals selected from each collection was relatively small compared to the collection as a whole. This was due to the individuals were selected with known trauma in order to develop a more predictable model. Not all of the individuals that are housed in each collection have this kind of data. This is especially true for the Donated Collection. In this collection, individuals have the option to fill out medical history data that may or may not include prior fractures and injuries. There was also incomplete data for some that is suggestive of accidental or intentional trauma, but is not fully clear. For example, an individual may write “fractured leg in 1945” and it is not clear if this is a wartime injury, or the result of a fall off of a house unrelated to the events that were playing out on a global scale at that time, particularly WWII. In addition, the demographic information may be missing for some individuals that would limit their use in the current analyses. The Forensic Collection was also vulnerable to some missing data, as these represent cases that may or may not have been positively identified. The same holds true for the Forensic Center data where the age, sex, and ancestry, as well as cause of death may be unknown.

The three collections were also not a random sample of the overall population. The reasons why an individual may or may not fill out this kind of information are variable and

unknown. In addition, the Forensic Center data was curated with an eye toward particular types of trauma that are fairly classic examples and that are useful for training purposes. There is an opportunity for missed trauma types in this kind of nonrandom collection. There is also a skew toward older, white males that is also represented in the current sample. The caveats of these types of collections have been discussed elsewhere, and are acknowledged as skewed but still capable of producing valuable information (De La Cova 2010). As it stands, this sample does represent multiple trauma types and is the best that all collections have to offer as far as known trauma. Therefore, the analyses still have some validity, though the results should be further tested on other samples.

Second, the variables that were chosen were selected with the intention of comparing the results of this study with the established literature. As such, demographic information was collected as well as counts for fractures. The addition of variables, such as bone class and fracture type, was meant to push the analysis into less explored areas of trauma research. The existing literature says much less about these features of fractures, so it was unknown if there would be significant results. The main variables assessed in trauma studies are therefore primarily made up of counts and categorical features of the trauma, which limits the kinds of statistics that can be run on this type of data.

Third, chi-squared analyses and logistic regression are applicable to categorical data, as they lack many caveats of ordinary least squares (OLS) regression and other general linear techniques. They do, however, have a tendency to be less robust than their OLS counterparts. In addition, they are also more difficult to interpret and require a broader knowledge base in order to apply the end results to practical applications. An example would be the pseudo R squares that are generated by a logistic regression analysis. These are similar to, but not the same as,

their OLS counterparts: true R square values. As such, it is more difficult to interpret their values. Despite this caveat, they are often still reported as individuals expect to see an R square value generated from a regression procedure (Agresti 2007; Stoltzfus 2011). In short, though the statistical analyses are acceptable for the data under study, they also come with their own limitations, which is typical of any statistic.

## **Future directions**

Future directions of study include increasing the sample size of the collections under study and broadening the variables included in the analysis. Increasing the sample size could be accomplished by adding individuals from the Hamann-Todd Collection, the Terry Collection, and other medical centers in the future. There is some cause of death data for these collections, but if the nature of injuries is to be known for inclusion in the sample, then there would be a small subset of the population that would be eligible to add. There is also the possibility of checking the model against such collections to see if it classifies accurately on these individuals. It should be noted, however, that these collections represent more individuals with earlier birth years (in the 1800's) than would be represented in the Donated, Forensic, and Forensic Center collections.

Additionally, the number of variables included would be slightly different for future analyses. Increasing the number of continuous variables may improve model fit, so size measurements for the injuries may be helpful to research. The length of a fracture in millimeters could be easily assessed. This may provide valuable insights into differences between accidental and intentional injury. In addition, it may also be fruitful to consider more data on the

directionality of injuries, such anterior-posterior versus medial-lateral. This may be another dimension of traumatic injuries that has the ability to differentiate between different types of trauma. Lastly, it would be helpful to add a higher number of women, and non-white individuals to the study, as there is a preponderance of white, males in the samples studied.

## Chapter 8: Conclusions

Overall, the present study is largely in agreement with the established literature on accidental and intentional trauma. It is interesting to note that there were few statistically significant deviations from the expected fracture counts among the sexes as concerns accidental versus intentional injuries, cause of death, region of injury, and the side of the injury. This is interesting to note as many studies focus on female victims, and fail to include aspects of male trauma for comparison. In addition, ancestry did not vary substantially from expected counts for accidental versus intentional injuries and region of injury, though there were some differences. This suggests that there may be other factors at work that affect the odds of sustaining an accidental or intentional injury with respect to ancestry. These differences, however, are likely an artifact of small sample size, and adding more individuals of non-white ancestries may reveal different vulnerabilities to injury.

The patterning of injuries throughout the body also followed the literature. Accidental injures showed fewer head/neck injuries and more injures of the thigh, leg, and arm, which follows predictions. In addition, there were more multiple injury sites than predicted for accidental trauma, which may indicate that this type of trauma is more diffuse and intentional trauma is more focused, which also follows the literature (Judd and Roberts 1998; Lyons et al. 2003; Martin and Harrod 2015). Similarly, the type of bone affected by these injuries also mirrored the literature, as more flat bones, which generally comprised bones of the skull, were affected by intentional trauma. Conversely, more long bones were affected than expected in the accidental group.

The type of fracture also varied by accidental or intentional injury and mirrored results found in other studies. Specifically, the majority of sharp force trauma was intentional, as was ballistic trauma, which falls in line with established literature and the intended uses of these weapons (Judd and Roberts 1998; Lyons et al. 2003; Martin and Harrod 2015; Sheridan and Nash 2007). Blunt force trauma was more prevalent in accidents, which is logical, as many trips, falls, motor vehicle accidents, and other accidents are more likely to result in this type of trauma (Christensen 2004; Teh 2003).

The logistic regression analyses indicate that there is promise for the application of these types of models to trauma data. The present results should be seen as a preliminary guide, however, as the sample was skewed toward white, older males and gives less power in discerning patterns outside of this group. In the future, more collections will be added to the sample in an effort to increase robusticity of model predictions for females and non-white individuals.

In closing, the overall pattern of injuries seen in this sample is generally in agreement with the literature on accidental and intentional trauma. Unknown individuals that present focused injuries of the head, neck, and face- as well as sharp force injuries of the trunk- should be investigated for other signs of deliberate injury. In contrast, unknown individuals that present more widely spaced injuries that predominately affect the appendicular skeleton, especially the legs, may be more likely to have suffered injury due to an accident. The current study is limited by small sample sizes for ancestry and non-random skeletal samples. Future research will tease apart more detailed patterns and associations between these types of injuries and what might better model and predict unknown trauma victims.

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## Appendix

## Worksheet for the Collection of Trauma Data in the Bass Collections and RFC

### Demographics and Codings

- 1) Age- Calendar years
- 2) Sex- Male (0) or Female (1)
- 3) Ancestry- White (0), Black (1), Hispanic (2), Unknown (3)
- 4) Cause of Death:
  - 0= Gunshot wound (GSW)
  - 1= Motor vehicle accident (MVA)
  - 2= MVA pedestrian
  - 3= Sharp force trauma (SFT) with a known weapon
  - 4= Blunt force trauma (BFT) with a known weapon
  - 5= MVA suicide
  - 6= GSW suicide
  - 7= Fall, trip, or jump
  - 8= Dismemberment
  - 9= Combination of causes
  - 10= BFT unknown weapon
  - 11= Unknown
- 5) Accidental (0) or intentional injury (1)

### Fracture Features and Codings

- 1) Fracture features:
  - a. Complete (1) or incomplete (0)
  - b. Bone Class
    - 0= Flat
    - 1= Flat and irregular
    - 2= Irregular
    - 3= Long
    - 4= Short
    - 5= Unknown
  - c. Type of fracture
    - 0= Blowout
    - 1= Combination
    - 2= Buckle
    - 3= Butterfly
    - 4= Circular
    - 5= Comminuted
    - 6= Crescent
    - 7= Crush

- 8= Cutmark
- 9= Depressed
- 10= Keyhole
- 11= Linear (general)
- 12= Multiple oblique
- 13= Oblique
- 14= Puncture
- 15= Radiating
- 16= Segmental
- 17= Unknown

2) Bone(s) affected-

- 0= Multiple cranial
- 1= Ribs
- 2= Vertebrae
- 3= Clavicle
- 4= Sternum
- 5= Ethmoid
- 6= Femur
- 7= Fibula
- 8= Frontal
- 9= Humerus
- 10= Hyoid
- 11= Os coxa
- 12= Lacrimals
- 13= Mandible
- 14= Maxilla
- 15= Metacarpals
- 16= Metatarsals
- 17= Nasals
- 18= Occipital
- 19= Orbit
- 20= Parietal
- 21= Phalanges
- 22= Radius
- 23= Sacrum
- 24= Scapula
- 25= Sphenoid
- 26= Tarsals
- 27= Temporal
- 28= Tibia
- 29= Ulna
- 30= Vomer
- 31= Zygoma
- 32= Nasal concha

- 33= Unknown
- 3) Side affected-
  - 0= Right
  - 1= Left
  - 2= Both
  - 3= Mid or non-paired
  - 4= Unknown
- 4) Region-
  - 1= Head
  - 2= Neck
  - 3= Trunk
  - 4= Upper arm
  - 5= Forearm
  - 6= Hand
  - 7= Thigh
  - 8= Lower leg (calf)
  - 9= Foot
  - 10= Multiple

## **Injury Features**

- 1) Mechanism of injury
  - 0= BFT
  - 1= Ballistic
  - 2= SFT
  - 3= Unknown
  - 4= Combo
  - a.
- 2) Timing of injury
  - a. Ante-mortem (0)skeletal features
    - Osteogenic reaction- resorption at fracture ends and/or callus formation
  - b. Peri-mortem (1) skeletal features
    - Fracture outline: v or u shaped
    - Fracture angle: obtuse or acute
    - Fracture edge: smooth but sharp, peeling/flaking
- 3) Injury sequence (if applicable)
- 4) Healing stage
  - a. 0- no bone proliferation
  - b. 1- slight bone proliferation
  - c. 2- open fracture with important bone proliferation
  - d. 3-healed fracture with callus formation and/or remodeling

## **Vita**

Shauna McNulty was born in Bergen County, New Jersey to the parents of Cheryl and Thomas McNulty. She is the first of three children and has a younger sister, Erin, and a younger brother, T.J. She moved to Englewood, Florida at the age of five where she attended Vineland Elementary School. She continued her education at L.A. Ainger Middle School and Lemon Bay High School in the same area. After graduation, Shauna pursued studies at the University of Miami in Coral Gables, Florida and earned a Bachelor's of Arts in Anthropology and French in May 2005. Her experiences in Forensic Anthropology courses pushed her to apply for the graduate program in Anthropology at the University of Tennessee, Knoxville. Shauna earned a Master's of Arts in Anthropology in August 2009 and continued into the Doctoral program at the University of Tennessee. Shauna will complete her Doctoral studies at the University of Tennessee in May 2016 with a Ph.D. in Anthropology.