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Paleoepidemiological Analysis of Trauma in a Roman Period Population from Kellis, Egypt, Circa 50-450 AD

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A thesis submitted in partial fulfillment of the requirements for the Master of Arts degree in Anthropology

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Abstract

This thesis analyzes human skeletal trauma in a large well-preserved sample (n =268) from the Roman period Kellis site in the Dakhleh Oasis, Egypt. Prevalence was determined for both infracranial and cranial skeletal trauma. The null hypothesis tested was that there are no differences in trauma when stratified by sex and by age cohorts (i.e., 18-35, 36-50 and 51+). Despite the overall trauma prevalence being similar between the sexes when not differentiated by age, the null hypothesis was rejected. Key differences that occurred between the sexes were that males suffered greater malintent and occupational traumas, whereas osteoporosis was the major contributor to trauma in older females. This is reflected in the age trends as males had a more linear pattern, while the female pattern peaks in the oldest age cohort. The research supports the conclusions that all studies of trauma should stratify samples by age and sex and investigate trauma using the individual as the unit of measure rather than separate skeletal elements.

Keywords

Trauma, paleoepidemiology, cranial and infracranial skeleton, odds ratio, malintent, interpersonal violence, occupational trauma, osteoporosis

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Chapter 1

2 Introduction

This chapter introduces the research query for this thesis in section 1.1. In section 1.2, the presentation of the remainder of the thesis is outlined.

2.1 Statement of the Problem

Trauma to the human body has been ubiquitous throughout our evolution (Steinbach 1976; Zivanovic 1982;). Most traumatic events do not, however, involve the skeleton, which greatly compromises the determination of the prevalence of trauma in archaeological populations. A corollary to this is that when the skeleton is affected the event probably involved more intensity, as it is much easier to damage overlying soft tissues than bone and even cartilage. Thus in the analysis of any trauma to the human body, regardless of the specific cause, the actual prevalence of bone trauma greatly underestimates the behaviour we are attempting to analyse. The interpretation of the causes of skeletal trauma is difficult but greatly aided by the medical profession (see Magnuson and Stack 1943), as the treatment of trauma has a long history in medicine dating back to the ancient Egyptians and Greeks (Jurmain 1999; Halioua and Bernard-Ziskind 2005). Clinical literature thus provides a template for determining the possibilities of the causes of given traumatic events, while the epidemiological literature provides a method of modeling the patterns of trauma and their causes in large population samples (Jurmain 1999; Waldron 2008). It is well known, for example, that the risk of trauma varies by sex and age, and thus populations have to be studied according to risk potential (Waldron 2008). For example, malintent trauma is usually more common in males than females and thus, samples studied have to separate this constitutional factor in order to estimate the overall prevalence (Buhr and Cook 1959; Larsen 1997). Also, damage to bone, particularly fractures, accumulates with age and thus the population under study has to be divided into well-defined age cohorts.

2.2 Outline

This thesis examines the prevalence of trauma in a large well-preserved Egyptian sample from the Roman Period from Dakhleh Oasis, Egypt (50-450 AD). The samples were excavated in the last two decades from two cemeteries associated with the town of Kellis as part of the bioarchaeology component of the Dakhleh Oasis Project (DOP). The study is restricted to the analysis of the adult (18 - 70 years of age) subpopulation of the Kellis sample (n= 268 skeletons). The null hypothesis (H_0) tested herein is that there are no significant statistical differences in prevalence between the different subgroups (males and females of different ages) in the population.

There are five additional chapters in this thesis. Chapter 2 places this research within the broader disciplines of paleoepidemiology and paleopathology. This is done through a brief overview of the history of these two disciplines and how this research is novel and relevant to the greater field of bioarchaeology. Chapter 3 illustrates how to identify and evaluate skeletal injuries in bioarchaeological samples. Using both clinical and paleopathological literature, the systematic process of classifying skeletal lesions that was used in this research is outlined. Subsequently, Chapter 4 provides the details concerning the materials used in this research as well as the methodological practices and techniques applied. An overview of the sample population, site history, qualitative, quantitative and statistical analyses used are provided. Chapter 5 discusses the results of the qualitative, quantitative and statistical analyses providing an overview of the skeletal injuries present in the sample population as well as the statistical results. Finally, Chapter 6 discusses how the results from this research can be used to improve and explore future avenues for studies of trauma within the broader context of human behaviour.

Chapter 2

3 Paleoepidemiological Studies of Trauma

This chapter outlines the historical and current approaches to studying trauma in the discipline of paleoepidemiology in section 2.1. The subsequent section, 2.2, focuses on certain limitations that arise when studying trauma in a mortuary sample. This idea is also elaborated on in Chapter 3.

3.1 Paleoepidemiology: Past, Present and Future

The study of disease in past populations has primarily been the purview of paleopathology. This line of inquiry had its genesis in the late 1800s with many focal changes since then. Historically the focus was on individual case studies (Aufderheide and Rodriquez 1998; Pinhasi and Mays 2008), which usually showed the pathognomonic lesions typical of diseases that afflicted westernized populations (e.g., caries sicca with syphilis, Potts disease with TB, etc.). In recent years, studies in paleopathology have moved to an epidemiological focus that integrates population data with statistics (Ortner 2011). Although case studies are still relevant and have been broadened with a new focus, as can been seen with the emergent research into the 'bioarchaeology of care' (Tilley 2012), a majority of studies now incorporate population levels of analysis. Examining disease prevalence at a population level and integrating paleoecology and ancient cultural data or historical sources has broadened the archaeological-historical questions to be examined. This paradigm shift involved the integration of epidemiological methodologies into the study of ancient human remains.

Epidemiology is broadly defined as a discipline inferring the causal relationships between risk factors (exposure) and a disease (outcome) (Pinhasi and Turner 2008). The discipline of paleoepidemiolgy is broadly defined as an interdisciplinary area that aims to adapt suitable epidemiological methods to study disease determinants in past human populations (Souza et al., 2003). A

major problem has been the adaptation of epidemiological methods to the cross-sectional nature of skeletal samples (Waldron 1994). Despite this, population-based paleoepidemiological studies have, however, allowed researchers to investigate questions regarding changes in the health status of past populations, changes in morbidity and mortality profiles and the prevalence of certain pathological conditions (Pinhasi and Bourbou 2007).

Trauma analysis in paleopathology has greatly benefited from both the clinical and epidemiological perspectives. The latter has provided a more quantitative and less subjective perspective, but requires background knowledge of the of the clinician-pathologist nature. Moving beyond the simple descriptive case studies of traumatic lesions and primarily focusing on the distribution, prevalence and relative frequency of traumatic injuries in a skeletal sample allows researchers to examine overall trends and patterns of trauma in past populations.

Historically, early research that can broadly be identified as paleoepidemiology involved a systematic method of collection and analysis of human skeletal remains. One of the first paleoepidemiological studies was conducted by Wood Jones' (1910) and investigated trauma using detailed data on fracture prevalence by individual elements in a sample of Lower Nubian skeletal remains. Roney augmented the use of epidemiological methods in paleopathology in a 1966 study that introduced the term paleoepidemiology in his analysis of ancient skeletons from California, although, his methodology did not include a systematic analysis of trauma. Such systematic analyses were sparse until Lovejoy and Heiple (1981) published their pivotal study of trauma of the Libben population in Ohio. These researchers clearly shifted the focus from descriptive case studies towards the use of paleoepidemiological approaches with an emphasis on quantitative analyses to delineate patterns of trauma within an archaeological sample.

As noted, shifting the research perspective from the individual to a population-level of analysis allows for the examination of patterns and trends within the sample population and the larger region. This creates a clearer picture of how and why certain types of trauma are present in archaeological remains. Using a systematic analysis of fracture prevalence within their skeletal sample, Lovejoy and Heiple (1981) set a precedent for using specific methods with clearly defined criteria (i.e., degree of preservation, age cohorts, ect.) for the inclusion or exclusion of skeletal elements within the calculated prevalence data. The methods from this study were adopted as a standard for collecting trauma data in skeletal populations, with a greater emphasis being placed on generating results that could be used in comparative studies with different archaeological sites (Bennike 1985; Jurmain 1991; Judd and Roberts 1999). Although trauma has been a topic of interest in the study of past peoples, there is a sparseness of population level studies, especially when framing trauma into the larger context of human behaviour. This paucity precludes the potential that trauma data have for reconstructing human behaviour in ancient populations, an issue left unaddressed in most paleopathological research (Larsen 1997). This issue persists today as the quantity of individual case studies far exceeds that of population-level analyses that can be used for comparative studies across the discipline. Even when the paleoepidemiological approach has been used the studies have not focused on the individual but bone elements such as long bones only (Glencross 2002), and have rarely addressed the impact that human behaviour may have on the presence or absence of trauma. By examining the underlying etiologies associated with specific traumas in the skeletal sample from the Kellis site, this thesis hopes to provide a better understanding of how trauma studies can move beyond prevalence data to consider the cause and effect relationship of trauma that was governed by individual and group behaviours in ancient Dakhleh.

The paleopathological literature divides trauma into categories including: fractures, crushing injuries, sharp-force wounds, dislocations, deformation, scalping, mutilation, trepanation, soft-tissue trauma, osteochondritis dissecans,

spondylosis, antemortem tooth loss (AMTL) and traumatic injury arising from pregnancy (Bennike 2007). However, many of these are difficult to differentiate at the proximate level. This thesis narrows the analysis of trauma and primarily focuses on fractures (including blade injuries) and dislocations. It is important to acknowledge that trauma may only affect the soft tissue and therefore may not necessarily be observed in the skeleton. Even when traumatic events do affect the skeleton, there is the possibility that over time (i.e., if the fracture occurs in childhood), bone remodeling will obscure evidence of a fracture having ever happened. Areas of interest in trauma-related studies often include domestic accidents, interpersonal violence and occupationally related trauma. Additionally, subsistence strategies, male pattern versus female pattern differences, availability of resources and nutritional status at the time of the fracture are areas of potential study (Roberts 2000; Molto 2015). A majority of the work in paleopathology has focused on injury resulting from interpersonal violence (Walker 2001; Brickley and Smith 2006; Tung 2007; Molto 2015) however; there have been some publications that deal with other types of trauma (Grauer and Roberts 1996; Larsen 1997; Judd 2004).

Paleopathological studies of trauma generally involve the presence of healed fractures and many of these reports have either focused the cranial or the appendicular skeleton, but rarely a combination of the two (Roberts 2000). It is important to note that it is the individual, not the site of the trauma that is interpretatively valuable. Sometimes this narrow view is due to poor sample preservation or the availability of certain skeletal elements within a sample population. For example, many museum collections in the past only included skulls. Due to the excellent preservation of the Kellis skeletal sample both cranial and infracranial skeletal elements are available for study.

3.2 Limitations of Studying Trauma in Human Skeletal Remains

The analysis of the behaviour behind a given trauma is amongst the most difficult tasks facing paleopathologists. Although bone fractures represent some of the



Figure 1. Burial K2 254 An example of a non-unified innominate.

most severe and identifiable forms of trauma to the skeleton, there are several limitations and caveats that must be observed when studying trauma in an archaeological skeletal sample. The first of these is deciding if the skeletal lesion under scrutiny is in fact trauma or a result of something else. This difficult task is heavily reliant on the individual researcher's skills and background. To illustrate, Figure 1 shows a potential traumatic lesion on the ishio-pubic ramus in the left hipbone of an adult female from Kellis estimated to be 30 ± 5 years of age.

Closer inspection shows that the apparent lesion is located in the precise area of union between the ischium and pubic bones, which usually fuses, in late childhood (Cardoso 2008). Knowledge of this is important, as it is possible that it reflects a genetic hypostasis or could reflect childhood trauma that caused the 'malunion'. This has been found in other areas of the skeleton such as the unfused acromial epiphysis, and even some cases of spondylolysis, which results from degenerative changes to the spine (Buikstra and Ubelaker 1994).

Perhaps one of the most challenging aspects of working with a mortuary sample is determining the precise time when a trauma occurred. For example,

head traumas in Kellis males were more likely to have been sustained when individuals are young and engage in riskier activities, although, if they live until the 6th decade of life, the trauma is recorded as present despite the event occurring in the younger years. Injuries can be divided into three main temporal intervals: antemortem or prior to death, perimortem or around the time of death and, postmortem or after death (Komar and Buikstra 2008). Although antemortem and postmortem injuries can most often be clearly differentiated with relative ease, injuries that occurred during the perimortem interval are difficult to define. As there is a delay before healing is visible macroscopically or radiograhpically, it is often difficult to distinguish between postmortem breaks and unhealed perimortem fractures. Distinguishing between antemortem and perimortem trauma is predicated upon different fracture properties associated with bone healing and the degree of remodeling seen at the injury site (Lovell 1997). Injuries may have occurred months or years before the estimated time of death and therefore it is difficult, if not impossible, to determine when an injury occurred during an individual's life, unless the injury occurred shortly before death and there is evidence of new bone formation (Roberts 2000).

In addition, post-depositional damage caused by tools such as trowels or shovels during excavation can be mistaken as trauma. Again the experience of the researcher is important to avoid these types of errors. Also, other taphonomic processes, which are events that act on an organism after death, may cause changes in the human remains that resemble traumatic lesions (Ortner 2003). Examples include bone breakage due to animal scavenging or anthropogenic disturbance of the remains by looters (Komar and Buikstra 2008). For example, a case involving two Iroquois crania at Lake Head University that were classified as having trauma related to trephination, however, upon further examination, the lesions were determined to be a consequence of rodent gnawing (Personal communication with Dr. Molto 2014). The hyperarid environment of the Dakhleh Oasis preserved the skeletons, and it is known that naturally occurring taphonomic processes did not greatly influence the state of the remains (Molto 2002a). However, looting was problematic at Kellis. Approximately 40% of the

burials at Kellis have been disturbed prior to excavation (Molto 2002a). Looting is not isolated to this skeletal sample and has been a major historic problem in archaeology. Generally, specific skeletal elements are selected (i.e., skulls), while the remainder of the burial is left, often exposed to the external environment and badly damaged. Although archaeological skeletal samples may contain thousands of individuals, the removal of selected skeletal elements can affect the true prevalence rate when determining the presence of specific pathological conditions within the sample. Despite the disturbance of the Kellis burials, the remains used in this research comprised of both cranial and infracranial skeletal elements and the assemblage was determined to be approximately 97% complete.

Chapter 3

4 Interpreting Skeletal Injuries: An Overview

This chapter outlines the current methodological practices of identifying and interpreting trauma in human skeletal remains. Section 3.1 focuses on how human remains are examined for injuries based on techniques derived from paleopathology. Section 3.2 illustrates the classification of traumatic injuries in bone based on the application of specific types of force and the resulting injury pattern. Section 3.3 highlights the valuable and restrictive applications of determining a timeline of injury in relation to an individual's death. In section 3.4, an overview of fracture healing and the complications associated with the healing process are given. Subsequently, the final section, 3.5, discusses the importance of establishing the ultimate mechanism of injury when assessing behavioural patterns in past populations.

4.1 Identifying Trauma in Human Skeletal Remains

In paleopathological literature, trauma is defined as an injury to living tissue caused by a force or mechanism extrinsic to the body (Lovell 1997). A description of traumatic injuries present in individual human skeletal samples is the first step in identifying and comparing trauma patterns within and between ancient populations. Categorizing injuries based on the proximate mechanism, type of trauma and approximate timeline of the event allow for both anatomical and sociocultural implications of the injury to be explored. This thesis focuses on not only identifying trauma in skeletal remains, but, classifying the trauma as it relates to environmental (accidental, occupational, geographical) and constitutional (age, sex, bone health, underlying pathologies) factors.

Current protocols for identifying and defining both cranial and infracranial traumatic injuries in archaeological skeletal populations are adapted from clinical, bioarchaeological and forensic science techniques. Despite the fact that traumatic damage to bone is common in archaeological samples (Ortner 2003),

interpreting injuries in antiquity is a complicated, multifaceted process that requires careful decision-making (Walker 2001). As noted, contemporary studies from both medicine and forensics play a large role in interpreting the type of trauma present in the skeleton as well as determining possible soft tissue complications that are a concomitant of certain traumatic injuries. These data are collected using autopsy reports, forensic case reports, living patient populations and experimental research using animal bones and human cadavers (Komar and Buikstra 2008). Due to the limited number of ways the skeleton can respond to trauma and the difficulty of attributing traumatic injuries to a specific cause, it is necessary to incorporate contemporary clinical and experimental studies on a comparative basis with bioarchaeological research to ensure that the best possible diagnosis can be made.

4.1.1 Determining the Mechanism of Injury

Mechanisms of injury can be direct or indirect causes of trauma, stress injuries or fracture in human skeletal remains. Intrinsic causes of trauma are linked to biological factors such as age, sex and health status and are recognized as proximate mechanisms of injury (Komar and Buikstra 2008). According to Roberts (2000), traumatic skeletal lesions are classified into the following categories: 1) a partial or complete break in a bone (fracture); 2) abnormal displacement or dislocation of a bone; 3) disruption of nerve or blood supply (a possible complication from a fracture); 4) artificially induced bone modification (i.e., foot binding or artificial deformation of the cranium). Osseous changes associated with trauma include unhealed fractures, exostoses from older injuries, remodeling as a result of joint dislocations and ossifications that occur within injured muscles, tendons and connective tissue that encapsulates bone (Walker 2001). A majority of trauma-related injuries that are present in the Kellis sample represent a range of osseous changes from minimal osteoblastic activity to callus formation to healed remodeling. Therefore, this work predominantly focuses on fractures and joint dislocations (such as humeral varus deformity) of both the cranial and infracranial skeleton. Evidence of trauma pertaining to surgical

intervention such as amputation or trepanation as well as cultural modification of bone, decapitation, cannibalism, dental trauma and soft tissue injury are beyond the scope of this paper. However, there are three cases of skeletal trauma in adults that likely represent cases of intervention during birth that resulted injury.

4.1.2 Dislocations

Trauma to a joint or surrounding area may result in a partial or complete dislocation. The total displacement of the articular surfaces of a joint is known as a dislocation or luxation. A subluxation refers to the partial displacement of the articular surfaces of a joint from one another (Lovell 1997). Dislocations and subluxations may be congenital or spontaneous in origin. However, damage to a joint capsule or ligament is generally associated with trauma and it is not uncommon for dislocations to be connected to fractures. A complication as a result from dislocations is the ossification of membrane, ligament and/or tendon attachments to the surrounding bone. This can lead to the instability of the joint and its reduced functionality; however, these complications may not be easily identifiable in archaeological human remains.

For the identification of dislocations in archaeological remains, the joint would need to have remained unreduced and bone modifications must have not taken place. It can be stated that dislocations are notably difficult to identify in mortuary remains. Dislocations are more frequently observed in young and intermediate age cohorts (Lovell 1997). A common site for dislocation is the glenohumerual joint as the shallow socket of the scapula makes the joint susceptible to displacement. Although this type of dislocation is salient amongst adults in clinical settings, there are unique forms of luxation that involve the glenohumerual joint that are rarely observed in archaeological skeletal samples.

In the Kellis skeletal sample, there are multiple accounts of unilateral and bilateral humerus varus deformity (HVD). This condition is rarely described in archaeological specimens (Molto 2000) yet occurs multiple times within the Kellis sample. Humerus varus deformity results in the proximal epiphysis being

displaced inwardly or medially from the longitudinal axis of the bone with subsequent shortening of the humerus. The skeletal elements affected are grossly deformed. Although HVD has multiple etiologies including genetics (mucopolysaccharidosis, thalassemia), infection and metabolic disorders, the cases in Kellis were likely a result of trauma that occurred at the time of birth and involved midwifery (Molto 2000).

4.1.3 Fractures

A fracture describes a partial or complete break in the continuity of the bone (Ortner 2003). There are several different types of fractures that can be classified based on the appearance of the lesion as well as its orientation with respect to the long axis of the bone. Discontinuities in the bone are produced by an abnormal application of force interacting with the intrinsic biomechanical and morphological properties of the bone itself (Agnew and Bolte 2012). Whether resulting from a sharp-force trauma such as a stab wound, or an accidental fall, fractures are common in archaeological skeletal populations. The severity and completeness (partial or impartial) of a fracture is governed by the intrinsic biomechanical properties of the skeletal element affected in conjunction with the direction and magnitude of the force involved (Komar and Buikstra 2008). As fractures to a bone can be dynamic or static, it is important to distinguish if the injury occurred acutely or over an extended period of time. Dynamic fractures result from a sudden high-force stress to the bone whereas static fractures are a result of a longstanding, usually, repetitive motion leading to a stress or fatigue injury (Larsen 1997). In addition, pathological fractures develop as a result of the bone being weakened by a previous condition (e.g., cancer) such that minimal amounts of stress can cause trauma (Roberts 2000). Fractures are defined based on the type of force that was applied to the bone and the resulting injury pattern. Direct force results in fractures at the site of impact, producing transverse, penetrating and comminuted fractures, whereas indirect trauma produces oblique, spiral and impacted fractures resulting from injury distant to the site of impact.

Fracture analysis begins with a detailed description of the lesion in order to establish the type of fracture and subsequently the type of force applied to sustain such an injury. Identifying the fracture in dry bone may also help to determine any complications that arose in the soft tissue. As previously stated, clinical studies regarding fractures not only examine the extent of the injury in the bone, but to the patient's soft tissue as well. Although evidence of soft tissue injury is rarely preserved in the archaeological record, a traumatic lesion present in an archaeological skeletal sample presumably would have impacted the individual who sustained the injury while alive. Complications associated with fractures include hemorrhaging, tissue necrosis, inflammation, nerve disruption or damage and infection (Ortner 2003). These complications could seriously impact the health of an individual and contribute to morbidity and mortality after sustaining a traumatic lesion.

4.2 Classification of Fractures

4.2.1 Direct Trauma

This subsection outlines protocols and classificatory criteria proposed by Lovell (1997) (Figure 2 and Figure 3) to describe the most common types of fractures observed in archaeological skeletal samples. A break occurring at the site of impact is referred to as direct trauma (Miller and Miller 1979) and the resulting fracture type is often transverse, penetrating, comminuted, crush or avulsion. A transverse fracture results from force applied in a line perpendicular to the longitudinal axis of the bone and is typically caused by a relatively small application of force delivered to a small area. Clinically, transverse fractures are caused by many behaviours such as hard kicks to the shin during soccer (Lovell 1997).

Penetrating trauma (both partial and complete) to the bone cortex is often the result of cutting or piercing and is classified as a direct trauma injury. Penetrating fractures are often a result of a large amount of force being applied to a small area. When examined in an archaeological context, penetrating

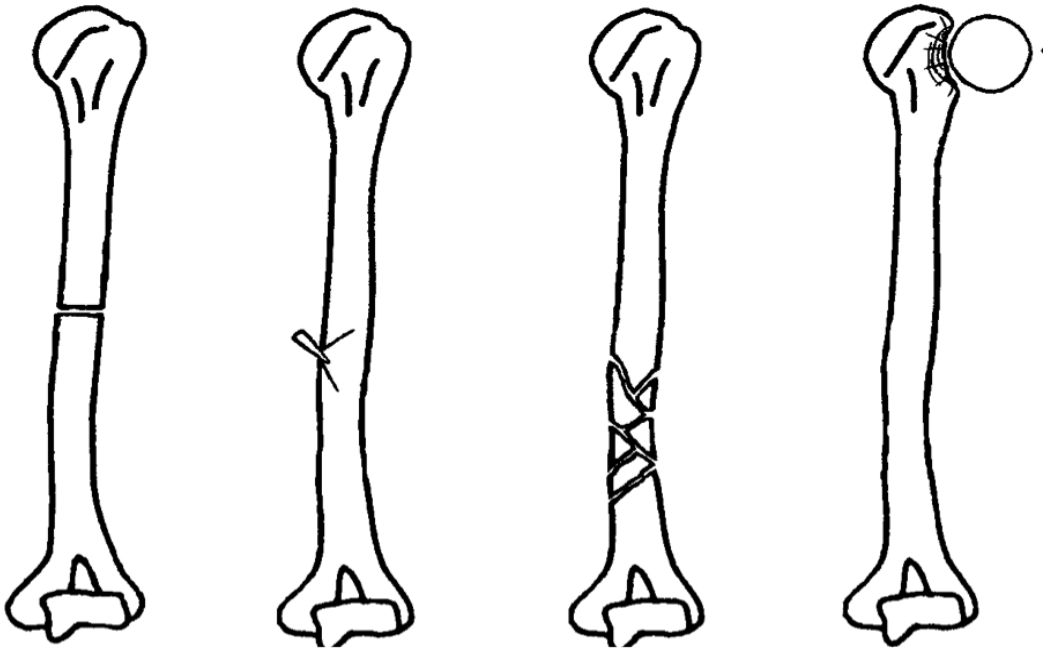


Figure 2. Fractures resulting from direct force. Left to right, transverse, penetrating, comminuted and avulsion. Image from Lovell 1997:142

injuries may result from a projectile point such as the blade of a knife or a sword, a wound from an arrow or spear, or a bullet wound (Larsen 1997). It is important to understand the cultural and temporal settings associated with the skeletal sample being analyzed to know which types of weapons were employed at the time. It is often difficult to determine the type of projectile point responsible for an injury, or the relationship between an injury and mortality, unless, the object remains embedded in the wound and there is no positive evidence of healing. Penetrating fractures may also be comminuted, which is when the bone is broken into several separate pieces. Comminuted fractures can also be the result of indirect force, which occurs when a force passes through the bone, leaving behind a distinct Y or T pattern and splitting the bone in several directions. In a clinical setting penetrating injuries are most often observed as the result of high velocity bullets (Walker 2001).

Crush fractures are most commonly seen in elements with large amounts of trabecular bone and result from the application of direct force, which causes the bone to collapse on itself. Crush fractures are organized into three categories: depression, compression and pressure. Depression fractures are the

result of crushing on one side of the bone- commonly seen on the cranium. Compression fractures result from crushing on either side of the bone and are also associated with low velocity impact. The third type of crush injury is a result of new bone reacting to a direct application of pressure, commonly seen in intentional modifications of bone such as cranial modification and foot binding. Crush fractures may sometimes be the result of indirect trauma, occurring from an individual falling or jumping from a great height and damaging their spine.

4.2.2 Indirect Trauma

An injury occurring in a place distant from the site of impact is known as an indirect trauma (Miller and Miller 1979) and often produces oblique, spiral, greenstick, impacted burst and avulsion fractures. Oblique fractures are characterized as having the line of fracture angled across the longitudinal axis of the bone, which is indicative of an angulated force. This type of break can be easily confused with a spiral fracture, which is a winding fracture line down around a long bone shaft due to a rotation and downward loading stress on the longitudinal axis. Spiral fractures are common in the lower limb bones as a result of the leg remaining rigid while the remainder of the body rotates (Ortner 2003).

Greenstick fractures result from the bone bending or buckling when stress is applied. This type of injury is more commonly seen in children as their bones are still pliable and tend to bend more easily (Komar and Buikstra 2008). Greenstick fractures are generally impartial breaks with only the convex side of the bone fracturing; in adults, this is common in rib fractures.

Additional types of fractures that are a result of indirect trauma include impacted, avulsion and burst fractures. An impacted fracture occurs when the force of the injury drives the bone ends at the fracture site into one another. This is seen in clinical cases in the proximal humerus as the result of a fall onto an outstretched hand (Lovell 1997). An avulsion fracture is caused from a torsional force tearing the joint, ligament or tendon away from the attachment site on the bone. This may cause a piece of the bone to detach from the site as well. This

type of injury is most common in the patella, where the muscles detach while the joint is rigidly flexed. A burst fracture is commonly seen in the spine and best represented by a Schmorl's node. This injury results from damage to the intervertebral disc, forcing the disc into the vertebral body and causes herniation into the adjacent vertebra.

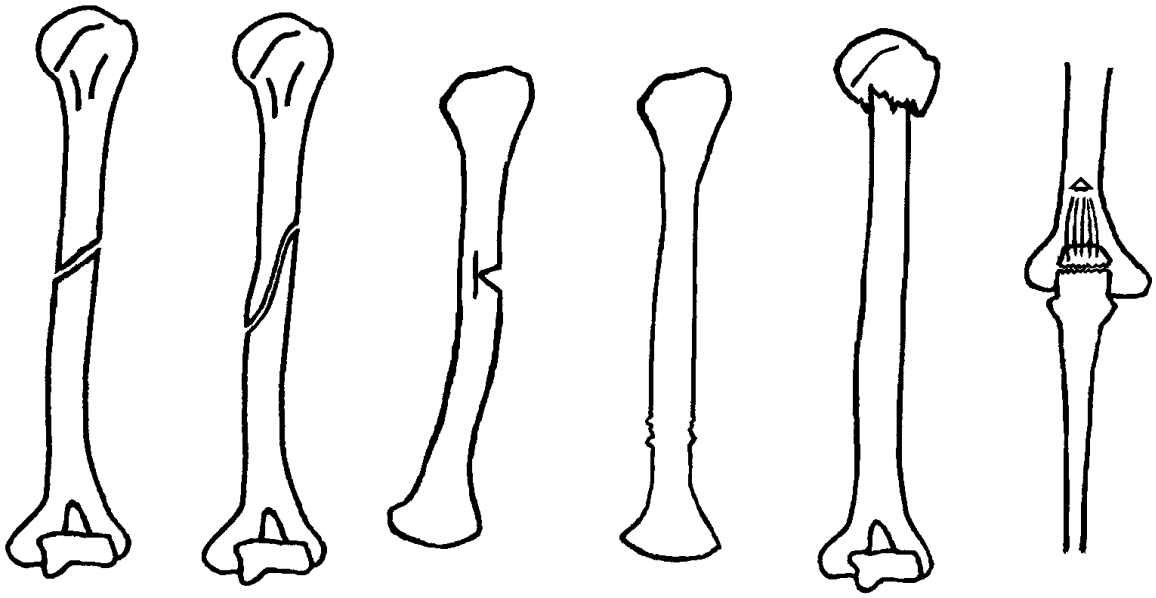


Figure 3. Fractures due to indirect force. Left to right, oblique, spiral, greenstick due to angular force, greenstick due to compression force, impaction and avulsion. Image from Lovell 1997:143

4.2.3 Stress Fractures

Fractures occurring over an extended time when chronic and/or repetitive force is applied to a bone are classified as stress fractures. This type of stress or fatigue fracture is usually found in the metatarsals, calcaneus and tibia (Ortner 2003). The repetitive stress of running is often associated with a large number of stress fractures on the lower limbs in clinical cases. Stress fractures are difficult to detect in archaeological skeletal samples as they are often incomplete breaks in the bone called hairline fractures, which are not easily observed macroscopically, and, are only detected radiographically when evidence of a callus is formed, resulting in an underrepresentation of this type of injury.

4.2.4 Fractures Secondary to Pathology

Fractures may also be classified based on the presence of an underlying pathology, which predisposes an individual to injury. The most common of these pathological conditions are systemic diseases, such as osteoporosis, which increases an individual's susceptibility to sustaining a fracture under minimal application of stress to a bone (Ortner 2003). Metabolic disorders, infections, developmental abnormalities and tumours are also known to predispose an individual to traumatic injuries by weakening the bone.

4.3 Establishing Timing of the Injury in Relation to Death

Determining the timing of the traumatic event is a daunting task yet, when possible, provides the researcher with valuable information pertaining to intrinsic and extrinsic variables surrounding the trauma (Walker 2001). The time in an individual's life at which a trauma event occurred is a particularly difficult aspect to determine in archaeological skeletal material, especially in the absence of historical documentation, cultural context or *in situ* analysis. When working with archaeological skeletal materials, it is often difficult to discern when a traumatic injury occurred due to many factors (e.g., bone reabsorption and remodeling processes). Injuries observed in dry bone may have occurred months or years before an individual's death, and it is not usually possible to estimate timelines, especially when the lesions are well-healed. To overcome this limitation, bioarchaeologists use three distinct time intervals to establish the timing of the injury: antemortem or prior to death, perimortem or around the time of death, and postmortem or after death. Distinguishing between antemortem, perimortem and postmortem fractures is predicated upon the different properties associated with the organic and inorganic composite of bone as well as the appearance of bone at various postmortem intervals (Lovell 1997). Antemortem and perimortem injuries are identified based on the presence and severity of several characteristics including evidence of inflammation and/or healing, the uniform presence of stains, soil or vegetative damage to the bone and the presence of oblique angles on the edge of the fractures. Fractures occurring after death are

identified based on a different set of characteristics including the absence/presence of small fragments of bone, squared edges at the fracture site, and the absence of fracture patterns due to the tendency of dry, brittle bone to shatter (Walker 2001). As there is a 2 to 3 week delay before healing is visible both macroscopically and radiographically (Ortner 2003), it is often difficult to distinguish between perimortem injuries and postmortem damage to the bone. In archaeological contexts, fractures observed are usually healed, indicating that the bone has undergone a considerable amount of healing and remodeling while an individual was alive, meaning that the injury was sustained antemortem although a specific timeline cannot be established. Due to the variation of the healing process between individuals and within the various skeletal elements of a single individual, if multiple injuries are present in the skeletal remains, it is not possible to distinguish if the injuries were caused by a singular event or sustained on multiple occasions. The most plausible conclusion that can be advanced is that the injuries were sustained sometime before death, however, this period of time remains indeterminate. Occasionally, when an injury occurred shortly before the time of an individual's death - 2 to 3 weeks prior- it may be possible to pinpoint a more exact time of when an injury was sustained however, caution must be exercised as the healing process can vary between individuals.

Postmortem injuries provide access to information regarding the post-depositional state of the remains and various taphonomic processes that impacted them. Furthermore, postmortem damage may be used to gauge the presence of human activity at the site. Activities such as farming, secondary burials and the looting of burials can create patterns of post-depositional damage in human remains (Komar and Buikstra 2008). However, due to the numerous factors that can contribute to postmortem damage of skeletal remains, identifying unique patterns pertaining to a single causative agent may not be possible. Understanding the depositional history of the site is valuable in reconstructing post-depositional and taphonomic history of the sample to discern possible contributing factors that may relate to postmortem damage.

4.4 Fracture Healing

Understanding the various stages of bone healing is vital to establish a timeline of traumatic injury. Fracture healing begins immediately yet the process differs for trabecular and compact bone and is highly variable between individuals, yet, bone healing follows a distinct biological pathway (Marsell and Einhorn 2011). The overlapping stages of healing that occur and the approximate time after injury for these processes is summarized here. The first visible evidence of fracture healing both macroscopically and radiographically is delayed for approximately 2 to 3 weeks after the injury. A callus of woven bone forms at the site of injury due to cell proliferation from the periosteum, marrow cavity and surrounding connective tissue. The callus stabilizes the injury internally and externally and bridges the gap between the fragmented bone ends (Marsell and Einhorn 2011). Subsequently, the callus of woven bone consolidates into mature lamellar bone. However, this process is idiosyncratic and highly dependent on the severity of the fracture and the type of bone involved.

In contrast to compact bone, trabecular bone has a much larger surface area of spongy connective structures with no medullary canal. The structure of trabecular bone facilitates the healing process and generally takes less time in comparison to areas with high levels of compact bone (Lovell 1997; Crowder and Stout 2011). This is a concomitant of the mesh-like structure of the trabecular bone allowing for a direct connection between the bone fragments rather than an indirect connection via the periosteal and endosteal callus as seen in compact bone (Lovell 1997). In both compact and trabecular bone, the bone remodeling process is lifelong and it changes the appearance of the fracture site overtime so that several years after the original injury, evidence of the fracture may be obliterated (Ortner 2003). It is important to note that although the process of fracture healing is organized into five stages, these are relatively arbitrary and may overlap into the next stage of healing, as the activities associated with each stage are unique for each individual. There are many factors that affect the rate and efficiency of healing including the fracture type, location, age of the individual

(younger individuals heal faster than older individuals), whether or not the fracture has had medical intervention and the presence of additional comorbidities.

4.4.1 Complications of Healing

The complications associated with traumatic injuries should be assessed in order to access information regarding morbidity, mortality and the presence or absence of medical intervention within the skeletal sample. Fractures can either have a “closed” or “open” relationship with the surrounding tissue (Komar and Buikstra 2008). Closed fractures occur under the surface of the skin and do not disrupt the epidermis. Open fractures, also called compound fractures, occur when the bone protrudes through the skin. This can lead to an increased susceptibility to pathogens invading the wound and subsequently causing infection. Skeletal tissue reacts to an infection with either a localized or a systemic response leading to the inflammation of various parts of the bone. The inflammation of the periosteum, known as periostitis, is called osteoperiostitis if skeletal tissue is affected. A more serious inflammation of the medullary cavity is known as osteomyelitis. Both osteoperiostitis and osteomyelitis are pathognomonic evidence of infection that were common in archaeological skeletal samples, especially before antibiotic treatment was available (Ortner 2003). Both of these forms of osseous response can result in serious complications including tissue death. In addition, fractures inevitably rupture blood vessels, which can result in tissue death due to ischemia. Another complication associated with fractures is the twisting of healthy blood vessels, leading to ischemia and potentially leading to a delay in healing or even worse, necrosis of the bone (Lovell 1997). Another common complication associated with fractures is nerve injuries. Damage can be temporary, only lasting a few days or weeks, or permanent, resulting in the loss of sensation and function. The extent and type of nerve damage is dependent on where the injury was sustained in the skeleton and its severity. Additional complications associated with fractures include loss of function and mobility in joints, the development of osteoarthritis, and/or the delayed union, nonunion or

the mal-union of the affected skeletal element (Roberts 2000). The frequency and severity of complications associated with healing vary amongst archaeological skeletal samples and can be used to make inferences regarding external factors that would have contributed to the outcome of traumatic injuries within a specific population.

4.5 Determining Possible Behavioural Mechanisms

Differentiating between accidental and intentional trauma is the fundamental basis of understanding how human behaviour influences patterns of trauma in archaeological skeletal remains. Even when the description of the traumatic injury has been completed, the proximate mechanism has been determined and the associated complications have been identified, the determination of the behaviourally-related cause of the injury provides the most valuable information regarding the patterns and trends of trauma within a skeletal sample. Assessing the characteristics of the fracture as well as the skeletal pattern of trauma in the individual, and in the population, in addition to any contextual information surrounding the human remains, is necessary to infer the ultimate cause of a traumatic injury. The behavioural interpretation of trauma is often attributed to accidental or violent events, however, underlying pathological conditions such as osteoporosis can significantly impact the frequency of certain skeletal lesions. General lifestyle conditions of a past population can be revealed through the assessment of skeletal injuries and the classification of such injuries into distinct behavioural categories. Assessing the type, prevalence and location of injuries within a population may give insight into the influences affecting past lifestyles. For example, a 2004 study by Judd revealed that skeletal remains from the ancient city of Kerma demonstrated fracture distribution patterns drastically varied from clinical injury distributions in two modern samples where falls were the primary mechanism of injury. The ulna and skull were among the least frequently injured bones in the modern samples while the radius, humerus and lower leg were amongst the most commonly injured elements amongst modern samples. The frequency of ulnar and skull injuries at Kerma were significantly

higher than the modern sample references and were consistent with blunt force trauma patterns observed in other clinical assessments (Judd 2004). The injury patterns documented in the clinical literature provide revealing analogies that can help bioarchaeologists understand the behavioural implication of similar injuries in the past (Walker 2001). The presence of these specific lesions in the Kerma population and the absence in the modern samples where accident was the primary injury mechanism presents evidence for interpersonal violence among the ancient Kerma people, suggesting that these injuries can be categorized as malintent (Judd 2004).

Accidental trauma encompasses injuries that occurred as the result of an accident and are often reflective of the hazards of everyday living and the daily interactions of humans and their physical environment (Larsen 1997; Lovell 1997). Intentional or malintent trauma is the result of violent interactions between individuals as the result of conflict. This reflects specific incidences of interpersonal violence that resulted due to possible stresses within the population such as a shortage of resources or warfare (Larsen 1997; Molto 2015). Some researchers (Angel 1974; Robb 1997) have attributed interpersonal violence to the development of gender roles that prescribed violent behaviour for males and reinforced the sexual division of labor in which females were not expected to perform activities considered violent or dangerous. The third category of trauma considered herein is osteoporosis-related trauma. This type of trauma is specifically related to the prevalence of osteoporosis in the older females of the Kellis sample and is reflected in specific trauma patterns that are associated with the condition. Although the underlying mechanism behind osteoporosis-related fractures is a pathology that increases an individual's susceptibility to fracture due to the weakening of the bone, these types of injuries can reveal information regarding ancient life and behaviour. For example, interpersonal relations among community members, attitudes towards others, environmental or occupational hazards, medical knowledge and also the consequences of injuries for the individual and the community (Kilgore et al., 1997; Mays 2006; Judd 2008). For example, if an older individual sustained multiple fractures that resemble injuries

related to osteoporosis, is there evidence of infection, medical care or any indication that the individual survived for a prolonged duration after the injury? Are there other individuals in the population suffering from the same injury and what can this tell us about the daily-life of the ancient people of Dakhleh.

When attempting to discern the behavioural cause of fractures in antiquity, clinical research has played a vital role in establishing the relationships between specific patterns of skeletal injury and the surrounding context (Larsen 1997; Lovell 1997). For example, fractures to the cranium, maxillofacial region, ribs and hands are more likely to indicate interpersonal violence than accidental injury (Lovell 1997; Ortner 2003; Komar and Buikstra 2008). In addition, injuries that have a high specificity for clinical diagnosis such as an assault or sharp-force trauma injuries from a weapon are more indicative of interpersonal violence than of an accident (Walker 2001). Using the characteristics of specific injuries themselves, some fractures are commonly associated with certain types of behaviour, such as the inferior to the midshaft ulnar fracture commonly referred to as a “parry” fracture, which is often characterized as the result of a direct blow when the forearm is raised to shield the face (Lovejoy and Heiple 1981; Judd 2008). However, identifying an injury predicated on that injury being the consequence of certain behaviours often leads to incorrect inferences on past lifeways. For example, the use of the term parry fracture may be used to describe the location of an injury as well as the accompanying social circumstances such as an interpersonal conflict or violent encounter. However, a true parry fracture has specific characteristics that are often not identified in paleopathological research. The following criteria must be met to classify an ulnar lesion as a parry fracture: 1) an absence of radial involvement, 2) a transverse fracture line, 3) a location below the midshaft, and 4) either minor unalignment in any plane or horizontal apposition from the diaphysis (Judd 2008). Although parry fractures are reported as one of the most common representations of interpersonal trauma in paleopathological research, this may be an overrepresentation of the actual prevalence of this type of injury. Thus, it is necessary to exercise caution when classifying injuries based on an assumed behavioural cause as these fracture

types and locations are usually not pathognomonic and require additional analysis on an individual basis.

Despite the interpretive problems, attempting to classify injury mechanisms related to behaviours allows bioarchaeologists to explore the cause and effect relationships pertaining to distinct variables, such as age and sex, and the possible outcome of a fracture within skeletal samples.

Chapter 4

5 Materials and Methods

The purpose of this chapter is to discuss the sample population used for this thesis, as well as the methods and techniques used in both the quantitative and qualitative analyses of trauma. Section 4.1 provides an extensive overview of the Kellis sample population including insights into geographical location, past subsistence patterns and the burial sites. Section 4.2 outlines the various qualitative, quantitative and statistical methods that were implemented during this research.

5.1 Materials

The archaeological database that represents the Kellis skeletal sample derives from two cemeteries associated with the Kellis town site (Figure 5). The sample population from Kellis has excellent cranial and infracranial preservation (Figure 4), which has facilitated isotopic, histological and genetic research, as well as detailed paleopathological examinations (Dupras 1999; Dupras and Schwarcz 2001; Molto 2001; Molto 2002b; Maggiano et al., 2006; Wheeler 2012). The wide range of skeletal elements available for examination allows for both cranial and infracranial patterns of trauma to be studied. Additionally, this sample includes individuals that have previously identified and documented cases of traumatic lesions.

5.1.1 The Dakhleh Oasis and the Kellis Skeletal Sample

The village of Kellis is located in the Dakhleh Oasis, Egypt, which is one of five major depressions in Egypt's western desert and is situated approximately 600 km SSW from Cairo. The Oasis is 100 km long from east to west and 25 km at its widest point from north to south (Cook et al. 1988). Current climatic conditions reflect those of the past: hot and dry with almost continuous sunshine and minimal rainfall. It has extreme seasonal variation in temperature with winter temperatures in the Oasis ranging from 2° to 25°C, and summer temperatures

reaching a maximum of 50°C (Cook et al. 1989). The average annual precipitation in the Oasis is approximately 0.03 mm and humidity rarely exceeds 50% (Dupras and Schwarcz 2001). Paleoclimatic studies indicate that the present hyperarid conditions are virtually identical to those during the Roman occupation of the Oasis (Giddy 1987). The current population of the Oasis is approximately 35,000 and is primarily sustained on agriculture grown in the iron oxide-rich soils (Churcher 1983; Fairgrieve and Molto 2000). Farmers in the Oasis produce vegetables, fruits (dates, apricots, oranges and olives) and cereals (rice, sorghum and wheat) for local consumption (Mills 1999). Occupants of the Oasis relied on local springs and artesian wells for water; however, under Roman administration, irrigation methods such as the *saqiya* were implemented to attract migrant farmers to the area (Molto 2002a). Excavated texts pertaining to agricultural accounts of the village of Kellis indicate that food was produced for both local consumption and trade suggesting that the village was prosperous during the Roman Period (Molto 2002a). During this time, it is believed that Kellis was more populated than earlier periods and was a major administrative and trading centre in Dakhleh. Noteworthy in terms of trauma analysis is that the villages in the Roman period were spaced out geographically and probably reduced the potential for intervillage conflict (Molto 2002a).

The Dakhleh Oasis has been a region of academic interest since 1978 under the auspices of the Royal Ontario Museum director A.J. Mills (Mills 1999). Since its inception, the Dakhleh Oasis Project (DOP) has focused on investigating the biocultural relationship between humans and the environment in Saharan Africa. The arid climate of the Dakhleh Oasis has resulted in the excellent preservation of organic material, including skeletal remains (as seen in Figure 4), soft tissue, botanical remains, textiles, papyrus and codices (Dupras and Schwarcz 2001). Excavations at the village of Kellis began in the 1990's and continued for over a decade. There has been considerable research conducted on the human remains from the Dakhleh Oasis that has indicated that the skeletal remains from this region have not experienced a considerable amount of diagensis and appear similar to modern human bone (Cook et al. 1989;

Fairgrieve 1993). Research previously conducted in paleogenetics using craniometric (Henderson 1993), skeletal and dental data (Molto 2001) to compare individuals from the Kellis samples relative to other Dakhleh samples indicate that the peoples of Dakhleh represent a single evolving deme over time. However, analysis of mtDNA indicates that in the Roman period there was greater heterogeneity due to an influx of people seeking out land for agricultural pursuits sponsored by the government (Parr 2002).



Figure 4. In situ burial 459 at Kellis.

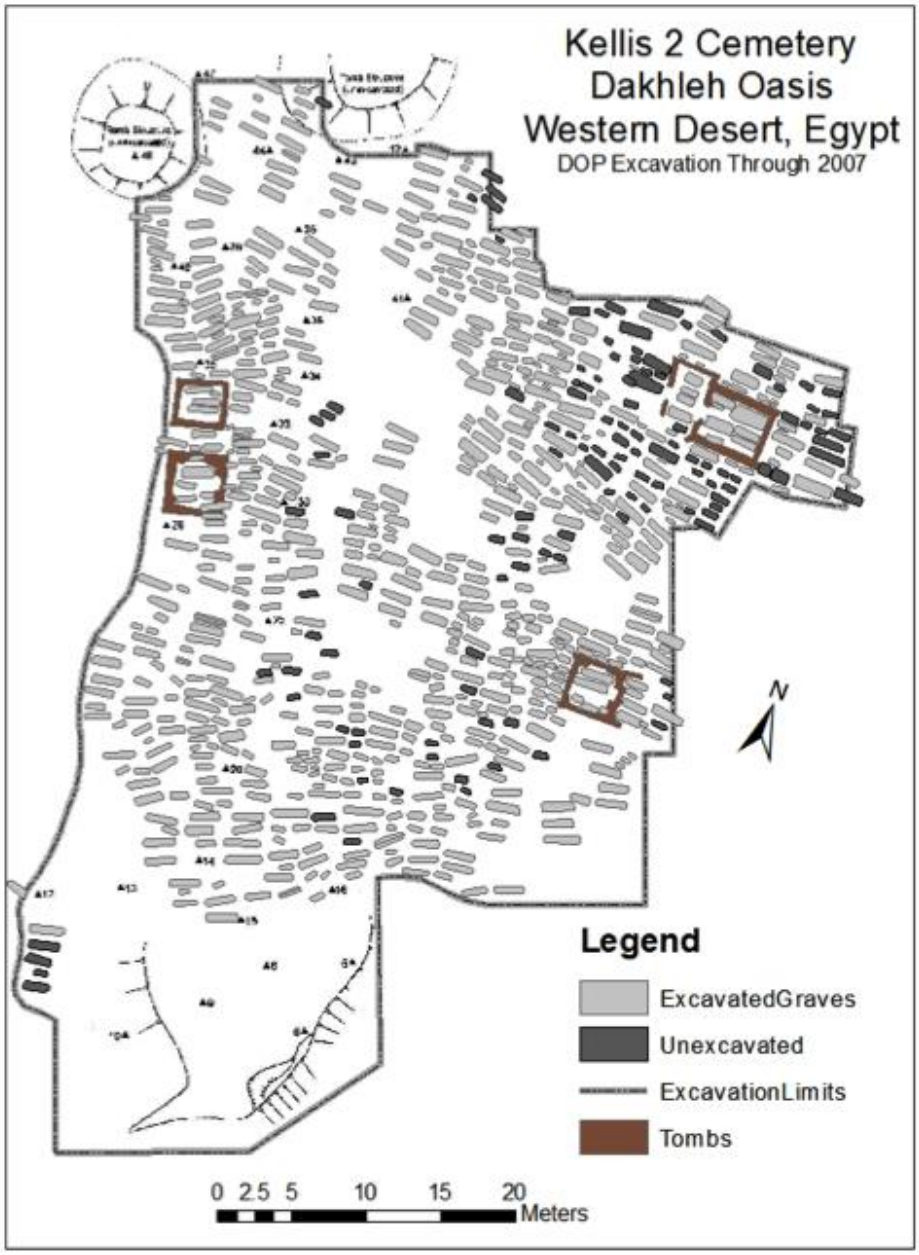


Figure 5. Kellis 2 Cemetery.

As noted, the skeletal material used herein comes from two cemeteries; one in the town of Kellis and the Kellis 2 (Figure 5), which is, located slightly northeast of the village. All the burials were single interments with the body positioned in the traditional Christian orientation: supine position east to west with the head facing west (Molto 2002a). Radiocarbon dates from skeletons in the K2 cemetery indicate that it was in use during the Roman period of occupation (50-450 AD) (Fairgrieve and Molto 2000; Molto 2000; Stewart et al., 2003). The village cemetery site contains burials similar to that of the Kellis 2 cemetery that have been dated to the Roman period occupation of the site. A total of 724 burials, 701 from Kellis 2 and 23 from the village have been excavated and analysed during the field seasons of the Dakhleh Oasis Project by Dr. J.E. Molto. Assuming that the density and distribution of unexcavated K2 burials is similar to those that have been exhumed, it is estimated that between 3000 and 4000 graves remain in the cemetery (Molto 2002). Despite the excellent representation of skeletal material in Kellis, a majority of the burials recovered to date (approximately 40%) have been anthropogenically disturbed (Molto 2002a). Looting is interspersed and has occurred throughout the cemetery, showing no difference in disturbance between male and female burials (Molto 2002a). Although several of the burials are disturbed, there is not a significant change in the representation of certain skeletal elements from the site and it is assumed that no biases were introduced into the sample. Despite the absence of certain skeletal remains, predominantly skulls, the amount of skeletal material recovered from the site remains numerically large. Due to the large skeletal sample available for study and excellent preservation of the human remains, the Kellis collection is ideal for conducting a population-level analysis of trauma.

The selected sample included males and females from different age-cohorts and individuals with and without evidence of trauma. Individuals with evidence of trauma were identified based on the presence of one or more discontinuities in the bone and macroscopic identification of bone remodeling and/or healing. This was recorded during excavations in the field and subsequently digitized in the Kellis Database. Dr. J.E. Molto of the University of

Western Ontario had previously determined the sex of individuals included in the sample through an assessment of the pubic symphysis (Phenice 1969). Each bone was tested in blind yielding 100% accuracy with minimal intra-observer error (Personal communication with Dr. J.E. Molto 2016). Only adult skeletons were included for this analysis due to the limited availability of sub-adult skeletons. Age estimations were based on published standards for dental attrition, pubic symphysis morphology and sternal rib ends (Brothwell 1981; Iscan and Loth 1986; Brooks and Suchey 1990). Individuals who could not be assigned a specific age range or accurate sex were not included in the sample population.

Table 1 Sex Distribution of the Kellis Skeletal Sample

Sex	Number of Individuals
Male	109
Female	159

*Sex estimates based on the methods described in Phenice (1969)

In addition, at the University of Western Ontario, I assessed the age of many individuals using the sternal rib ends from the Kellis skeletal sample (following: Iscan and Loth 1986). This test was done in blind and yielded similar age designations to those previously assigned to individuals by Dr. J.E. Molto.

A total of 268 individuals were selected from the Kellis cemetery sites (109 males and 159 females) with ages ranging from 18 years of age to over 70 years of age (see Table 2). Why there is a disparate sex ratio (see Table 1) remains speculative (Kearne 2015). Bone preservation was not discriminated by side (left and right) and an equal degree of bone preservation was seen throughout all age ranges and both sexes (Teeter et al., 2015). Although the preservation of human remains from the Kellis site is excellent, only skeletal elements that were at least 2/3 complete were included in the sample. This was to prevent an over-

representation of the number of skeletal elements present. The majority of the skeletal sample is comprised of nearly complete skeletons.

Table 2 Age Profile for the Kellis Sample

Age Cohort	Number of Males	Number of Females
18-35	57	71
36-50	35	43
51+	17	45

*Based on ageing methods from Brothwell 1981; Iscan and Loth 1986; Brooks and Suchey 1990

5.2 Methods

The population-level analysis of trauma of the Kellis skeletal material began with the organization of osteological information into a digitized database. The records available for each individual in the sample population were inserted into a tabulated data system organized by age and sex. Creating a database that contains detailed information about each of the skeletal elements recovered at the Kellis burial sites is important for not only this study, but to preserve information for future research as access to the study collection, which was predominantly reburied after excavation, will be limited. Working with a database also allows researchers to investigate the meaning behind their results, by having access to large quantities of data, which can be subjected to rigorous statistical tests. The research design for this thesis was largely built on the incorporation of both descriptive (prevalence data) and analytical epidemiological methods to measure the differences between frequencies of trauma within the sample population. Examining the role that various constitutional factors (age and sex) play in the etiology of trauma in the Kellis skeletal sample population was examined with both quantitative and qualitative techniques.

5.2.1 Defining the Sample Population

Individuals were assigned into one of three discrete age cohorts based on morphological characteristics (Brothwell 1981; Iscan and Loth 1986; Brooks and Suchey 1990) younger adults range from 18-35 years of age, intermediate adults range from 36- 50 years of age and older adults encompass 51 years of age and older. The distribution of individuals within each cohort can be seen in Table 2. These broad age cohorts were chosen to accommodate the difficulties that can be associated with ageing older adults in archaeological skeletal material without losing age-specific information (i.e., clustering all adults into the same cohort). Placing individuals into specific age cohorts allows for an investigation into the patterns and trends associated with different aspects of a lifecourse and how factors such as age and sex may influence the patterns observed. For example, 29 out of the 45 females (64.4%) in the older adult age cohort (51+) were affected by trauma. The rate of trauma in the older female age cohort is significantly higher in comparison to the rates of trauma in the younger (8.5%) and intermediate (20.9%) female cohorts. Observing the change between age cohorts is only the start into the inquiry. Is this change related to age? Sex? Activities? Attempting to understand the age and sex variation between the cohorts is a major goal of this research.

5.2.2 Data Organization

The individual burial information was organized into an Excel spreadsheet by burial number, sex and age. A detailed skeletal inventory was conducted for each individual using any osteological information previously recorded including osteobiographies, field photographs and field notes. Both side and completeness of the skeletal elements recovered were recorded as well. The following elements were included in the database: cranium, clavicle, humerus, radius, ulna, hip, femur, tibia, fibula, ribs and vertebra. The metatarsals and metacarpals were also recorded, but they were not included in this research due to poor sample availability. Also, the ribs and vertebra were not recorded by individual element due to time limitations in the field (Personal communication Dr. J.E.

Molto 2016). The presence of trauma in a skeletal element was denoted by a "9" while the absence of trauma was denoted by a "0"; additional comments pertaining to the individual were included in a subsequent comments section. If the skeletal element was missing in the collection an "A" was used to indicate the absence. A description of any trauma present as well as the presumed proximate mechanism of injury was noted for affected skeletal elements and recorded in the database. Fractures were classified according to their predominant characteristics to prevent a single cause from immediately being inferred before all possible evidence had been considered (Lovell 1997). For example, a parry fracture implied a violent etiology, which is not necessarily true for all ulnar fractures (Judd 2008). This type of injury results from different causes including falls, which is the predominant cause in modern populations (Domett and Tayles 2006). In total, over 5142 skeletal elements were recorded in the database and by comparing the presence of skeletal elements versus the expected number of skeletal elements for both the male and female subgroups, it was calculated that 97% of the skeletons included in this study were relatively complete (at least 2/3 of the skeletal elements were present for each individual).

5.2.3 Prevalence

Once all traumatic lesions had been identified, prevalence rates were determined. Fracture prevalence was recorded for both skeletal elements and individuals. For this thesis, prevalence is based on the number of skeletal fractures shown by an individual upon their death. As paleoepidemiological samples are cross-sectional in nature and represent an accumulation of fractures over a lifetime, the term 'incidence', defined as the number of new disease cases arising in a population at a specific period of time, is not used to describe the data (Waldron 1994). Multiple measures are used to describe fracture prevalence in the Kellis sample population.

5.2.4 Statistical Analysis

The research design for this thesis was largely based on the incorporation of both descriptive (prevalence data) and analytical epidemiological methods to measure the differences between frequencies of trauma. Examining the role that various exposures and activities play in the etiology of trauma in the Kellis skeletal sample population was examined with both qualitative and quantitative techniques. As noted in Waldron's (1994) comprehensive review of applying epidemiological methods in paleopathology, the limited use of analytical epidemiological methods within the discipline should not overshadow the useful application of such techniques when measuring the differences between the frequencies of a disease using an odds ratio. The methodology used in this

Table 3 Odds Ratio Calculation

	Trauma Present	No Trauma Present
Male	A	B
Female	C	D

Odds ratio- (A/C)/ (B/D)=AD/BC

study undertaken in the reverse order of a cohort study, emphasizing the cases that have been selected as matching certain criteria (Waldron 1994). The initial starting point in the statistical analysis was to define an outcome variable. The outcome variable in this study is the presence of skeletal trauma. This study group representing the Kellis skeletal sample population was selected using the following criteria: adult individuals, known age-at-death, known sex, and clear evidence of macroscopically visible trauma. The lack of x-rays may have underestimated the overall prevalence trauma. The control group was selected using same criteria with the exception of not having visible trauma present.

The next analytical stage determined what events or exposures are similar throughout the population. The researcher's preconceived notions about the

trauma causation generally influence this. Based on evidence from histological studies of bone (Crowder and Stout 2011), the human ageing process (Brickley 2002) and previous trauma studies (Molto 2002a; 2010), it was established that the type of trauma observed in skeletons is often dependent on the age and the sex of an individual. Thus, age and sex were determined to be exposures that influence the etiology of trauma.

Using the odds ratio formula illustrated in Table 3, the odds ratio for fracture risk was determined for all three age cohorts for both the male and the female sample population. Calculating the odds ratio at a 95% confidence interval (CI) is useful to determine if the results were statistically significant. The odds ratio was interpreted by assessing the value in terms of the effect of exposure to risk (Table 4).

Table 4 Interpreting Odds Ratios (from Sahai and Khurshid 1996)

Value	Effect of Exposure to Risk
0-0.3	Strong negative
0.4-0.5	Moderate negative
0.6-0.8	Negative
0.9-1.01	No effect
1.2-1.6	Weak positive
1.7-2.5	Moderate positive
= or >2.6	Strong positive

Additional statistical testing incorporates the 95% confidence interval (CI) to determine the statistical significance of the odds ratio. Using a significance value of P= 0.05, if P < 0.05 the value is determined to be statistically significant. A

significance value less than or equal to 0.01 indicates highly statistically significant results.

5.2.5 Analysis of Traumatic Lesions

Using the injury descriptions available in the database in conjunction with clinical and previous paleoepidemiological studies, skeletal trauma in the Kellis sample was analysed in an attempt to classify each traumatic injury into one of the following behavioural categories: malintent, accidental, occupational and other diseases (e.g., osteoporosis related). The underlying behaviour associated with a particular type of traumatic injury may reveal the ultimate cause of the trauma. Once the estimate of disease prevalence is obtained, it is necessary to estimate its effect on the population thus providing a greater understanding of local conditions in the past. As the people today have a similar lifestyle to the ancient Kellans this is a very useful interpretive parameter. When determining the ultimate cause behind any injury, three types of information must be considered: 1) the characteristics of the fracture itself; 2) the skeletal pattern of trauma in the individual and population; and 3) the social, economic, historical and/or environmental contexts of the human remains, including the presence of artifacts (Lovell 1997). Moving beyond simple counts of lesions as the primary means of characterizing the disease experience in past populations allows for a greater understanding of which particular and even perhaps why certain traumas are happening at certain times in an individual’s life (Milner and Boldsen 2011).

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Chapter 5

6 Results

This chapter summarizes the results of the qualitative, quantitative and statistical analyses of trauma in the Kellis sample population. The results are provided in the following subsections: 5.1 provides summary descriptions of elemental trauma rates; section 5.2 summarizes prevalence data pertaining to elemental fracture rates as well the distribution of elemental fracture patterns. Section 5.3 provides a quantitative analysis of the trauma in the various age/sex groupings with an emphasis on the risk associated with injury and the mechanism of injury for individuals. Section 5.4 summarizes the results of the application of the odds ratio test to assess the trauma risk. Risk assessment was conducted using an odds ratio calculation with a 95% confidence interval. These calculations are used to determine overall prevalence patterns and associated exposures (age and sex) viewed in the archaeological context of the Kellis population sample. Finally, section 5.5 provides a brief summary of the results chapter.

6.1 Summary of Trauma by Skeletal Element

The descriptions of the lesions are organized by skeletal element and all types of skeletal trauma are presented together. This reporting by skeletal element is necessary as most comparative data provide trauma by skeletal element and not by individuals for various reasons (e.g., selective sampling-only skulls collected, poor preservation etc.). The traumatic lesions are discussed in terms of their specific qualitative characteristics through a descriptive analysis. Figure 6 indicates the skeletal elements analyzed in this study.

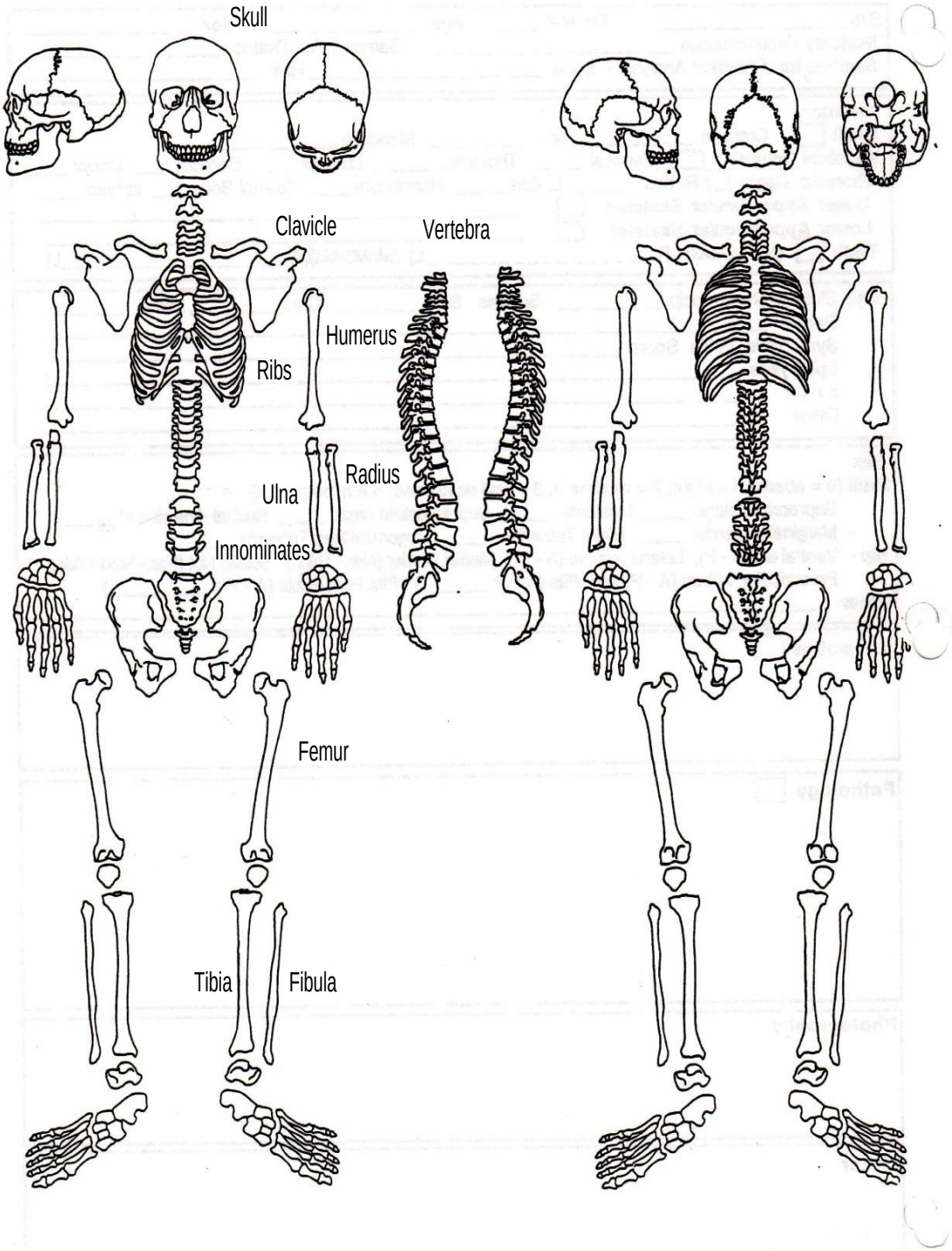


Figure 6. Skeletal elements included in this study.

6.1.1 Skull

Twenty-one fractures were observed in 205 skulls (15/80 male and 6/125 female).

In males, four of the fractures occur on the right, three occur on the left and eight out of the fifteen occur in the nasal region. Four fractures occur on the parietal region, three occur on the frontal region (Figure 7) and as noted eight occur in the nasal region. In the females, two fractures occur on the right side of the skull, four occur on the left side of the skull. No fractures were observed in the facial region. Two fractures occur in the frontal region of the skull and four fractures occur on the parietal region.

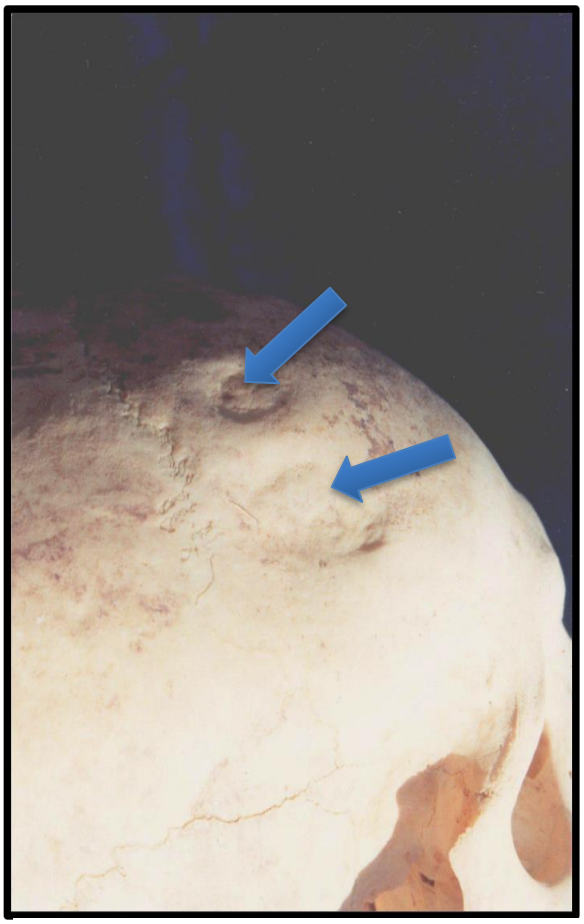


Figure 7. K2 199 Male, age 35, depression fractures on the frontal bone of skull.

Four of the six fractures (one frontal and three parietal) are classified as depression fractures (Figure 7). The remaining lesion is classified as a healed linear bone fracture which transverses the left frontal bone. It is important to note the variation in fracture location between the male and female subgroups. Males experience a higher rate of injury to the facial and nasal region (8/15) whereas no facial injuries were recorded in the female sample. Injuries occurring in the facial region in clinical settings are often associated with interpersonal violence, such as hand-to-hand- conflict (Walker 1997; Brickley and Smith 2006). This suggests that men

may have been involved in more face-to-face conflict than their female counterparts. It does not, however, suggest that women were subjected to less interpersonal violence than men, as the transverse sharp force fracture on the left frontal bone implies. There are other patterns that must be considered when identifying behaviours associated with specific injury patterns, which will be discussed later in this chapter.

6.1.2 Clavicles

Eleven fractures were observed in a total of 507 bones (257 right, 250 left). Six fractures occur on the right side and five on the left side with six observed in males (6/203) and five observed in females (5/308). The clavicular fractures were all healed.

6.1.3 Humerii

Four fractures occurred in a sample of 513 humerii (259 right, 254 left). All four of the fractures occurred in males (4/202). In addition to fractures, there were also three recorded cases of humeral varus deformity (HVD). Two cases of HVD were recorded in males (2/202) and one case was recorded in a female (1/311). Humeral varus deformity is interpreted as a response to birth trauma with possible mid-wifery intervention (Molto 2000). Thus the sex difference is of little significance.



Figure 8. K2 8 Female, 70+, healed Colles' fracture of the right distal radius.

6.1.4 Radii

Fifteen fractures occurred in a sample of 513 radii (258 right, 255 left). Fourteen of the fifteen fractures occurred in females (14/312). A majority of these fractures were characterized as Colles' fractures located on the distal end of the radial bone (Figure 8). Ulnar involvement was present in three of the fourteen radius fractures occurring in the females. Although not possible to distinguish between multiple and singular events, falling with an outstretched hand often leads to injuries involving the displacement of both the radius and ulna (Grauer and Roberts 1996).

6.1.5 Ulnae

In a sample of 521 ulnae (260 right, 261 left), six fractures were present. Three fractures occurred in males (3/205) and three occurred in the female subgroup (3/316).

In the females, two of the three individuals also had radial injuries. One female in the intermediate age cohort had healed injuries to the left ulna and left radius in addition to two shallow depression fractures; one healed, one unhealed of the left posterior parietal bone. Elemental patterns involving the distal forearm and cranium are often characterized as defense wounds resulting from an attempt to ward off a blow to the face (Jurmain 1991; Judd 2008). In the males, one individual in the intermediate age cohort had a parry fracture that was confirmed by x-ray. The trauma present was characteristic of a lesions resulting

from the application of a blunt force to the proximal third end of the bone, a pattern associated with a defense wound (Jurmain 1991).



Figure 9. K2 191 Female, 70+ with a healed intertrochanteric fracture. This fracture was well-healed and resulted in the formation of a pseudoarthropy.

6.1.6 Hips

Of 512 hipbones, 10 showed fractures, eight of which occurred in the female cohort (8/313). One female in the intermediate age-cohort had fractures of the right hip, sacrum, first left metatarsal and fourth right metacarpal. Field notes indicated that the bones were well mineralized and osteoporosis is not believed to be a concomitant factor. The remaining seven fractures occurred in individuals belonging to the older age cohort with each having multiple traumas. One older female had a healed fracture of the right ischio-pubic ramus and a compression deformity of L1. As the hip fracture was healed, it is difficult to determine if osteoporosis was a contributing factor. The six remaining fractures occurred in older females that were identified as having widespread osteoporosis in the skeleton (based on field observations). These fractures are summarized as follows: a female aged 70± showed evidence of a healed fracture of the left ischio-pubic ramus. Whether or not this is a concomitant of the widespread osteoporosis seen throughout the skeleton is difficult to determine as the fracture is well-healed. Another specimen from the older female age cohort displayed multiple healed fractures, likely from a major fall years before her death. The injuries present included fractures to both hips, the right clavicle, ribs, left distal ulna, lumbar vertebrae, sacrum as well as metacarpals and metatarsals. Another complete female skeleton was noted as being very osteoporotic with a

concomitant fracture of the right ischium, sacrum and an unhealed fracture of the femoral neck. There was soft tissue embedded in-between the femoral head and neck which indicates that the femoral fracture was perimortem. In addition, a female estimated age 60 displayed evidence of an unhealed fracture of the trochanteric region of the left hip in addition to an unhealed left femoral fracture; osteoporosis was widespread throughout the skeleton. A female with an approximated age of 70 displayed similar osteoporosis-related fractures of the left ischial pubic ramus, femoral neck, femoral head, sacrum, thoracic vertebrae, lumbar vertebrae and advanced degeneration of the spine.

Of the two hip fractures occurring in males, one individual belonged to the younger age cohort and suffered from a fracture of the right hip, sacrum and ribs. Osteoporosis was not present in the skeleton. The second individual is from the intermediate age cohort and had a healed penetrating trauma to the left ilium. It is important to note that in contrast to the female subgroup, there were no hip fractures in the male subgroup that were associated with Type 1 osteoporosis. The females who suffered from hip fractures presented evidence of multiple traumas, often to one or more of the following elements: femoral neck, ribs, distal radius, metacarpals, metatarsals and spine.

6.1.7 Femora

Of 521 intact femora, 12 had fractures; with equal side prevalence (6/261 in right and 6/260 in left). A majority of the fractures, 10/312, occurred in females with only 2/209 occurring in males. The distribution and location of the femoral fractures followed a similar pattern to what was observed in the hip fractures. In the females, all ten of the femoral fractures occurred in the oldest age cohort and were classified as intertrochanteric fractures (Figures 9 and 10) associated with osteoporosis.



Figure 10. K2 B82 Female, 60+, unhealed intertrochanteric fracture.

Five of the fractures were healed; five were healing or unhealed, which indicates that death occurred shortly after the fracture event. All females suffering from intertrochanteric fractures had multiple fractures, most commonly to the vertebral column and ribs. In the males, one individual from the youngest adult age cohort had a well-healed fracture of the right femoral neck that was not accompanied by any other pathology. Another male from the oldest age cohort had an avulsion fracture of the greater trochanter of the right femur that likely occurred prior to the ossification of the epiphysis accompanied by a fracture of the right clavicle, ribs and compression fractures of the spine.

6.1.8 Sacra

Fractures occurred in 8 of 260 intact sacra; three (3/104) males and five (5/156) in females. Of note is that all sacral fractures were accompanied by multiple injuries. In males, one individual in the youngest age cohort had fractures of the sacrum, right hip and ribs. The remaining two fractures affected individuals in the oldest age cohort; one individual had both nasal and sacral fractures while the other male had a sacral fracture accompanied by a vertebral fracture. In the females, one intermediate-aged individual had a sacral fracture accompanied by a fracture of the right hip. The remaining four fractures occurred in individuals in the oldest age cohort. Three of the four individuals with sacral fractures had accompanying hip fractures, which are associated with the same event (e.g., a fall). One individual had both a sacral fracture and a frontal skull lesion.

6.1.9 Tibiae

Of the 526 complete tibiae, three fractures were present; all in males (3/214). Two occurred in the intermediate age cohort; one individual had a healed fracture of the left tibia, skull and ribs, whereas the second individual suffered a severe trauma to the left side of the skeleton, with evidence of healed fractures of the left tibia, left fibula, left radius and left ulna. The third was an older individual with evidence of healed trauma to the right tibia and right fibula (Figure 11). The tibial fractures are interpreted herein as the result of occupational trauma that



Figure 11. K2 324 Male, 55+, healed fractures of the distal tibia and fibula.

probably occurred long before his death. The fact that these bones were not set (i.e., realigned) suggests limited medical knowledge within the Kellis community as such bones today would be aligned as close as possible to their natural stress lines.

6.1.10 Fibulae

In 529 complete fibulae, four fractures were present, all in males (4/216). Two fractures occurred in the intermediate age cohort; one individual had evidence of healed trauma to the left side of the skeleton, with fractures of the left fibula, left tibia, left radius and left ulna. The second individual had trauma to the right fibula and ribs. The remaining two fractures were to older individuals. One individual had evidence of healed trauma to the right fibula and tibia (Figure 11) presumably from a major fall. The poor alignment of the bones in Figure 11 would have had a negative impact on the individual's gait. The second individual had a healed fracture of the right distal tibia with evidence of periosteal bone growth on the shaft, possibly due to infection.

6.1.11 Vertebrae

In this study, the vertebral column was included in the skeletal inventory if 2/3 of the column was present. Most often the vertebrae missing were in the cervical region due to looting. In total, 264 vertebral columns were analyzed, 23 of which had compression defects. Seven of the fractures occurred in males (7/107) whereas sixteen of the fractures occurred in females (16/157). In males, three of the seven fractures occurred in the younger age cohort, with each individual having multiple traumas. Two of the individuals from this cohort have evidence of sharp-force trauma, specifically, penetrating vertebral wounds representing evidence of malintent. The remaining four fractures occurred in older individuals, with four individuals having multiple traumas. Two of the four fractures were characterized as compression injuries.

In females, there are significantly more vertebral fractures than in males. Two of the fractures occurred in individuals belonging to the younger group; both

being single traumas. Two individuals in the intermediate age cohort suffered from compression defects of the thoracic and cervical spine. One individual had a T1 wedge deformity that resulted in the ankylosis of the adjacent vertebra. The second individual showed evidence of Schmorl's nodes in L3, L4 and the compression of C5 and C6. Both individuals had widespread osteoporosis. The remaining 12 fractures were in older females. Eleven of these twelve individuals had multiple traumas, the majority of which were associated with osteoporosis. Nine of the twelve fractures had evidence of at least one collapsed vertebrae, anklylosing of adjacent vertebrae or the presence of Schmorl's nodes.

6.1.12 Ribs



Figure 12. K2 B227 Male 23(±3.6 years) unhealed stab wounds to the left 8th and 9th ribs.

Although ribs were not counted by individual bone herein, ribs were included in this analysis as they are commonly affected in antiquity (Roberts and Manchester 2005). If nearly complete rib bones were present in the burial, these ribs can be attributed to one person, as the graves in Kellis were single interments. For the purpose of this analysis, individuals were identified as having rib bones present or absent; complete sets of rib bones were not required in order for these elements to be included in the study as a means of increasing the number of

individuals present in the sample population. There were 263 individuals in the sample with rib bones present; forty with fractures. Twenty-three affected individuals were males (23/106) and seventeen were females (17/157). Rib fractures were common in both sexes and all age-cohorts within the sample population. Two young adult males had unhealed rib fractures that were produced by sharp force trauma that penetrated the cortex of the rib bone (Figure 12). Rib fractures in females were primarily found in older individuals (12/17) usually with multiple traumas primarily associated with osteoporosis (i.e., hips, femur, distal radius and vertebrae). Since all the rib fractures were healed it is difficult to determine if they all occurred in older individuals, but no doubt many of these occurred because of an increased susceptibility to fracture in older women.

6.2 Elemental Fracture Rates

6.2.1 Elemental Prevalence Rates

Prevalence rates for each skeletal element in the Kellis population are presented in Table 5. From the previous section, it was noted that there are several examples of individuals with multiple traumas present.

There were a total of 157 fractures in the Kellis sample. The highest prevalence occurred in the ribs, which accounts for 15.2 % of the 157 fractures. As shown, the ribs had the highest prevalence in both sexes. The skull also had a high rate of involvement with a prevalence value of 10.2% followed by the vertebrae (8.7%). As this research is concerned with the distribution of fractures in relation to age and sex, trauma was further investigated according to males versus females in terms of the various age cohorts.

When the data were organized by sex, they showed that there is not a significant overall difference in the prevalence of trauma between males and females. As seen in Table 6, the male and female cohorts show similar patterns such as rib fractures being most common in both sexes followed by cranial trauma. However, the ultimate causes of the fractures within each of the subgroups are variable. For example, osteoporosis is a well-known contributing

risk factor to injuries in post-menopausal females (Mensforth and Latimer 1989; Brickely 2002; Agarwal and Stout 2003). In the older female cohort of the Kellis sample population, eight individuals had intertrochanteric fractures likely from falls juxtaposed on demineralized bones (Molto and Sheldrick 2011), whereas no males had intertrochanteric fractures in the older cohort.

Table 5 Elemental Rates of Trauma

Element	n	p	%
Crania	205	21	10.2
Clavicles	511	11	2.2
Humerii	513	4	0.8
Radii	513	15	2.9
Ulnae	521	6	1.2
Hips	521	10	1.9
Femurs	521	12	2.3
Sacrum	260	8	3.1
Tibiae	526	3	0.6
Fibulae	529	4	0.8
Vertebrae	264	23	8.7
Ribs	263	40	15.2

n= number of skeletal elements

p= number affected by trauma

Table 6 Prevalence of Trauma in Males versus Females

	Males			Females		
Element	n	p	%	n	p	%
Crania	80	15	18.8	125	6	4.8
Clavicles	203	6	3.0	308	5	1.6
Humeri	202	4	2.0	311	0	0.0
Radii	201	1	0.5	312	14	4.5
Ulnae	205	3	1.5	316	3	0.9
Hips	208	2	1.0	313	8	2.5
Femora	209	2	1.0	312	10	3.2
Sacrum	104	3	2.9	156	5	3.2
Tibiae	214	3	1.4	312	0	0.0
Fibulae	216	4	1.9	313	0	0.0
Vertebrae	107	7	6.5	157	16	10.2
Ribs	106	23	21.7	157	17	10.8

n= number of skeletal elements

p= number affected by trauma

As shown in Table 6, 21.7% (23/106) of males had rib fractures (all but 2 were healed) followed by cranial prevalence of 18.8%. The vertebrae followed with 7 observed lesions (6.5%). The remaining elements are organized into descending trauma rates: clavicle (3.0%), sacrum (2.9%), humerii (1.9%), fibulae (1.9%), ulnae (1.5%), tibiea (1.4%), hips (1.0%), femurs (1.0%) and radii (0.5%).

Similarly to the males, Table 6 demonstrates that the females had the highest prevalence of trauma in the ribs (10.8%), followed by the vertebrae (10.2%). The remaining elements are organized into descending trauma rates: the skull (4.8%), radii (4.5%), femurs (3.2%), sacrum (3.2), hips (2.5%), clavicles (1.6%) and ulnae (0.9%). There were no fractures recorded for the humeri, tibiae or fibulae in the females.

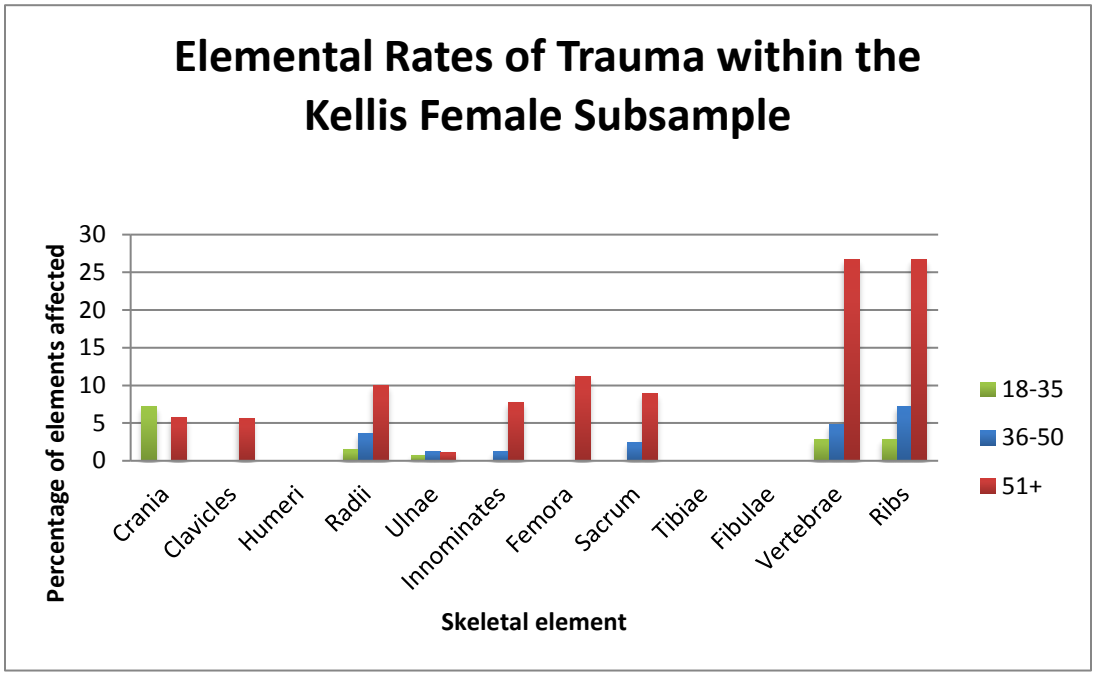
6.2.2 Sex and Age Specific Rates of Trauma

This section further stratifies the data based on sex and age specific cohorts to examine the patterns of trauma that emerge when comparing individuals across and between cohorts.

6.2.2.1 Prevalence of Female Trauma by Age

Figure 13 shows the prevalence of female trauma by element and by age cohort. It is evident that there are certain skeletal elements that are more at risk for traumatic injuries during certain times in an individual’s life. The most dramatic variation between the female age cohorts occurs with the increase in the trauma rate of the radius, hip, femur, ribs and vertebrae with age. Although fractures may be cumulative and reflect the injuries that individuals have sustained throughout a lifetime, it is my opinion that most of the fractures suffered by females in the older cohort actually occurred during the postmenopausal years and are associated with the systemic bone loss resulting from osteoporosis. This hypothesis will be discussed further in Chapter 6.

Figure 12 Elemental Rates of Trauma within the Female Cohort.



Noteworthy with these data is an inverse relationship between rate of trauma in the female crania with age. As age increases, the prevalence of trauma to the crania decreases in the Kellis female population. This obviously is a stochastic result, as young individuals who suffer trauma would show these lesions when they reach an older age. This result illustrates the innate difficulties of dealing with a cross-sectional mortality sample.

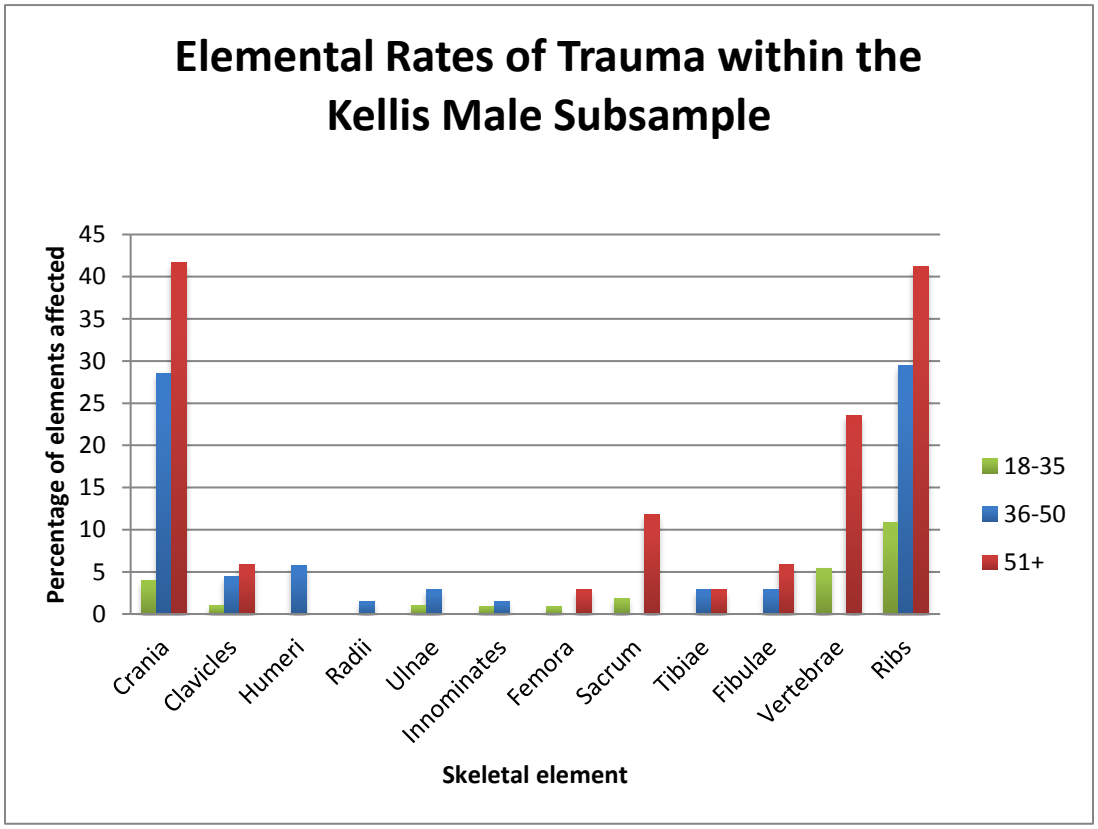
In the female infracranial skeletons, the most common lesions occurred in the vertebrae and ribs of older individuals (51+), with 26.7% of the elements recovered showing evidence of trauma (12/45 for both vertebrae and ribs). The older female cohort also had a highest prevalence of trauma observed, likely due to the influence of osteoporosis. Recall that of the 89 femurs observed, 11.2% had fractures and all of these were in oldest cohort. This is a significant increase in comparison to the younger and intermediate female age cohorts, as neither had any evidence of trauma in the femur. Similarly, the hip and radii data from the older age cohort (7.8% and 10.0% respectively) were greater in comparison to the younger (0% and 1.4% respectively) and intermediate (1.2% and 3.6%

respectively) age cohorts. In addition, the older female cohort showed a higher rate of trauma in both the clavicle (5.6%) and sacrum (8.9%) relative to the earlier age cohorts.

As noted, the age pattern in female crania is stochastic with the highest prevalence (7.1%) occurring in the young adults. There was no cranial trauma in middle-aged females. The distribution of the cranial lesions was mainly concentrated on the parietal (4/6) and frontal (2/6) areas with no facial lesions involving the nasal cavity. The lack of facial lesions suggests limited face-to-face malintent trauma in females, an opposite trend was observed in the male subsample.

6.2.2.2 Prevalence of Male Trauma According to Age

Figure 13 Elemental Rates of Trauma within the Male Cohort.



Males have a similar pattern to females in regards to the direct relationship between increasing age and increasing elemental rate of skeletal trauma. However, the elements that experience an increased prevalence of trauma are different between the two sexes.

Males experience a higher rate of trauma in the younger age cohort than females, although similarly to the females, the highest rate of trauma is found in older males. For example, in comparison to the younger males, the older males have nearly ten times the rate of elemental trauma in the skull (4%, 41%). A similar increase can also been seen in the trauma rate of the ribs which has a gradual increase as age increases. In comparison to the intermediate aged males, older males have higher rates of trauma in virtually all the skeletal elements.

6.3 Fracture Prevalence: By Individual

As noted, the sampling strategy used to produce the fracture prevalence data is cross-sectional, where *N* is the total number of subjects in the sample and each subject is scored for the absence or presence of pathology. As trauma in adults reflects the accumulation of trauma events over time it is difficult to assign exact rates for each succeeding cohort.

6.3.1 Individual Prevalence Rates

Table 7 Age and Sex Distribution of Fracture Prevalence by Individual

Age Cohort	Males				Females			
	P/N	%	M/P	%	P/N	%	M/P	%
18-35	10/57	17.5	(4)/10	40	10/71	14.1	(1)/10	10
36-50	19/35	54.3	(9)/19	47.4	9/43	20.9	(2)/9	22.2
51+	14/17	82.4	(8)/14	57.1	29/45	64.4	(15)/29	51.7
Total	43/109	39.5	21/43	48.8	48/159	30.2	18/48	37.5

P= number of individuals affected by trauma

N= total number of individuals in cohort

M=number of individuals affected by multiple traumas

The above elemental analysis (Table 6) of trauma was used, in part, for comparative purposes as many studies only record elements affected by trauma, particularly skulls. However, it is the individual that experiences traumatic events. This section summarizes the data by individual, which is possible because of the excellent preservation and representation of the Kellis sample (see Table 7). This table also includes the category of multiple traumas per individual. When a person presents with multiple traumas it is often difficult to determine if the injuries represent single or multiple events.

In total, 91 (34%) of the 268 individuals (sexes and age cohorts combined) showed at least one fractured skeletal element. The number of individuals with multiple traumas is also summarized in relation to the overall number of individuals affected by trauma in each age cohort. In total, 39 (14.5%) of the 268

individuals showed evidence of two or more fractured elements. Males and females respectively were almost equally affected (39.5% versus 30.2%); although these data can be misleading because the reasons for multiple traumas are very different between sexes especially when the trauma is well-healed.

In Kellis males, occupational and interpersonal risks can produce multiple lesions per individual whereas in females the most important contributing factor is bone density (e.g., osteoporosis). For example, of the 51.7% of females with multiple traumas in the oldest age cohort, most of the individuals were very osteoporotic. In contrast, older males have no evidence of osteoporosis-related fractures. The similar high rates of overall trauma in the males and females with major age-related differences are best understood as the result of the differential lifetime risks. Fracture prevalence in mortality samples is cumulative. Each age cohort has a different length of exposure to risk of a fracture, the oldest age cohort (51+) having the greatest length of exposure. Understanding this is germane to understanding the ultimate causation of trauma for a given population. This is partially resolved by accounting for age within the sample population. This problem could possibly be addressed by using person years exposure (Glencross and Sawchuk 2003) but, this technique is problematic because of the large variance in age estimates especially for older adults. In the older female cohort most of the fractures were a product of osteoporosis during their later years; this can be confirmed through the condition of the skeleton as well as the presence of multiple traumas. Note that the fracture rates in the two early age cohorts in females are extremely low compared to the older (50+) adults. Clearly, the lifetime risk of skeletal trauma is virtually the same between males and females (i.e., 39.5% and 30.2% respectively), but the causes of the traumas and the patterns are significantly different. The statistical results demonstrate this.

6.4 Statistical Analyses Results

Using the odds ratio for the Kellis trauma sample facilitates a more in-depth analysis of the potential risk of fractures in relation to age and biological sex.

Odds ratios were computed to understand the associations between bone fractures and the variables sex, element and age based on guidelines by Sahai and Khurshid (1996) for interpreting odds ratio calculations. The 95% confidence interval (CI) for the odds ratio value can be used to estimate the precision of the odds ratio (Szumilas 2010). A large CI indicates a low level of precision, whereas a small CI indicates a higher precision of the odds ratio (statistical significance is denoted with an asterisk (*)) (Szumilas 2010). A 95% confidence interval is not an exact measure statistical significance; however, it can be used as a proxy to statistical significance if the odds ratio does not overlap the null value (OR=1). A confidence interval that spans the null value cannot be used to measure the association or lack of evidence between an exposure and an outcome.

6.4.1 Fracture and Biological Sex

Table 8 Stratified Analysis Output for the Association Between Fracture and Exposure by Sex

	Odds	Odds Ratio	95% Confidence Interval
Male	0.6515	1.5066	0.9029-2.5141
Female	0.4324		

The sex-specific odds ratios indicate that males are 1.5 times more likely to sustain a fracture than their female counterparts. Although males have slightly greater odds of sustaining a fracture relative to females, the association between risk of fracture and biological sex is a weak positive. The 95% confidence interval (0.9029, 2.5141) encompasses values ranging from a weak effect through a strong effect, indicating that the result does not have a high level of precision. As noted above this computation is biased, as it does not consider age and the underlying causes of the traumas.

6.4.2 Fracture, Total Number of Elements and Biological Sex

Table 9 Stratified Analysis Output for the Association Between Fractures, Total Number of Elements in Males versus Females

	Odds	Odds Ratio	95% Confidence Interval
Males	0.0368	1.3189	0.959-1.814
Females	0.0279		

The sex-specific odds ratios indicate that males have a slightly elevated number of fractures relative to the total number of skeletal elements recorded in the sample. Males are 1.3 times more likely to sustain a fracture; this value is considered to be a weak positive. The confidence interval indicates the effect of the exposure by element as being weak to moderate as unity (=1) is encompassed in the range.

6.4.3 Fracture, Biological Sex and Age

This section examines both the exposure of sex and age in association with the outcome of a fracture. The results are summarized for the three age-cohorts in Tables 10 through 12.

Table 10 Stratified Analysis Output for the Association Between Fracture and the Younger Age Cohort (18-35), Males versus Females

	Odds	Odds Ratio	95% Confidence Interval
Male	0.2128	1.2979	0.4992-3.3745
Female	0.1639		

These data indicate that males are nearly 1.3 times more likely to sustain a fracture compared to females belonging to the same age cohort. This value is interpreted as a weak positive association. The 95% confidence interval has low precision since values include no effect through strong effect (0.4992, 3.3745).

Table 11 Stratified Analysis Output for the Association Between Fracture and the Intermediate Age Cohort (36-50), Males versus Females

	Odds	Odds Ratio	95% Confidence Interval
Male	1.1875	4.4861	1.66-12.0855*
Female	0.2647		

The odds ratio for testing the association between fracture, sex and the intermediate age cohort can be interpreted as a strong positive, 4.5>2.6. This association shows that males are 4.5 times more likely to sustain a fracture during this time period in their life in comparison to females belonging to the same age cohort. The 95% confidence interval supports this assessment and includes values of moderate to strong association.

Table 12 Stratified Analysis Output for the Association Between Fracture and the Older Age Cohort (51+), Males versus Females

	Odds	Odds Ratio	95% Confidence Interval
Male	4.667	2.5747	0.6424-10.32
Female	1.8125		

The odds ratio testing the association between fracture, sex and the older age cohort can be interpreted as a strong positive. Males that are over 51+ years of age are 2.6 times more likely to sustain a fracture than their female

counterparts. The 95% confidence interval is not informative since the intervals include values ranging from no effect through strong effect (0.6424, 10.32). As previously stated, although both males and females in the older age cohort have a longer exposure to the risk of fracture and therefore a high chance of accumulating more fractures throughout a lifetime, the variation in the distribution of fractures between the two sexes suggests that there are other variables influencing individual risk of fractures. For the oldest female age cohort, the main exposure that contributes to an increased risk of fracture is the presence of systemic osteoporosis, which does not appear to be a risk factor in older males.

6.4.4 Multiple Fractures, Sex and Age

From the prevalence data in section 5.3, it can be seen that there are several individuals in the sample population that suffered from more than one trauma to the skeleton. The presence of multiple fractures can be the result of simultaneous or independent events. However, when working with mortality samples, it is often difficult, if not impossible, to determine if an individual's injuries are the result of more than one insult to the skeleton (Judd 2002). Notwithstanding this interpretation, the risk of obtaining multiple fractures within and between the cohorts is a valuable method of determining the presence of underlying variables contributing to an individual's risk of fracture. Table 13 demonstrates that when males and females are compared independently of age, the risk of sustaining multiple fractures is only 1.3 times greater for males than females. The earlier prevalence data indicated that males and females were relatively similar, 48% and 38% respectively, in terms of the number of individuals who were affected by one or more traumatic injuries. However, the prevalence data also indicated that the distribution of individuals with multiple fractures was highly variable when age is considered as an exposure.

Table 13 Stratified Analysis Output for the Association Between Multiple Fractures in Males versus Females

	Odds	Odds Ratio	95% Confidence Interval
Males	0.4884	1.3023	0.6139-2.763
Female	0.375		

Table 14 Stratified Analysis Output for the Association Between Multiple Fractures and Exposure by Biological Sex and Age: A Comparison Between The Youngest Age Cohorts

	Odds	Odds Ratio	95% Confidence Interval
Males	0.6667	6	0.5321-67.6525
Female	0.1111		

Table 15 Stratified Analysis Output for the Association Between Multiple Fractures and Exposure by Biological Sex and Age: A Comparison Between the Intermediate Age Cohorts

	Odds	Odds Ratio	95% Confidence Interval
Males	0.9	3.15	0.5149-19.2719
Female	0.2807		

Table 16 Stratified Analysis Output for the Association Between Multiple Fractures and Exposure by Biological Sex and Age: A Comparison Between the Oldest Age Cohorts

	Odds	Odds Ratio	95% Confidence Interval
Males	1.3333	1.2444	0.3443-4.4978
Female	1.0714		

The data presented in Tables 13-16 demonstrate that the risk of sustaining multiple traumatic injuries greatly varies by age. Table 14 compares the male and female samples in the youngest age cohort and shows that males are 6 times more likely to sustain multiple fractures in comparison to females. This finding corroborates the earlier data showing that males from the Kellis sample population sustained more cranio-facial wounds that were associated with violent injury than females in the younger age cohort. Judd has reported similar findings in her 2004 study of injury recidivism in a Nubian skeletal sample; younger males displayed a much higher frequency of multiple injuries associated with violence (facial wounds, parry fractures, penetrating wounds, ect.). The use of the 95% confidence interval in Tables 13 to 16 was not effective as the ranges for each table encompassed values from no effect to extremely high effect and contained unity.

Similar to the findings of Table 13, Table 15 shows that males have a slightly higher risk of sustaining multiple injuries (odds of 3.15) than their female counterparts. As age increases, it appears that the risk of sustaining multiple injuries is nearly equal between males and females. Table 16 demonstrates that males are only 1.2 times more likely to suffer from multiple injuries in comparison to females in the same age cohort. However, it is known that fracture prevalence and frequency in mortality samples is cumulative. Thus, it would be expected that both males and females experience a greater and relatively equal risk of

sustaining multiple injuries as age increases. To demonstrate the confounding effect that this may have on individual fracture risk, Table 17 shows the odds ratio calculations for the risk of multiple traumas comparing the youngest and the oldest female age cohorts.

Table 17 Stratified Analysis Output for the Association Between Multiple Fractures and Exposure of the Female Cohort: A Comparison of the Youngest and Oldest Age Cohort

	Odds	Odds Ratio	95% Confidence Interval
18-35	0.1111	9.6429	1.0785-86.0171*
51+	1.0785		

When age is examined independently of biological sex, it can be seen that there is a significant risk of sustaining multiple fractures with increasing age. From Table 17, females that are 51+ are 9.6 times more likely to sustain multiple skeletal injuries than females who are between 18-35 years of age. The 95% confidence interval supports this significant result, surpassing unity and ranging to a strong positive effect (1.1-86.0).

When stratifying data based on age and sex, odds ratio values are indicative of some association between these two exposures and the outcome of a fracture. Confounding variables must be considered when examining the relationship between two or more exposures and a particular outcome. If a non-causal association is observed between a particular exposure and a given outcome, this may be the result of a third variable known as a confounding variable. This variable may be causally associated with the outcome and non-causally or causally associated with the exposure (Szumilas 2010). Stratification is one method used to address confounding variables. To examine the relationship between age and fracture risk, data were further stratified based on sex. Females and males are independently assessed in the next section.

6.4.5 Fracture, Female Cohort and Age

The sex-specific odds ratios comparing the likelihood of a fracture between the various female age cohorts indicate a significantly higher risk of fracture in older age cohorts versus the younger age cohort. Table 18 summarizes the odds ratio values between the youngest and intermediate age cohorts and is indicative of a weak positive association. The 95% confidence interval is not informative as the range includes values from no effect through strong effect. The odds ratio value for Table 19 which compares the intermediate and oldest age cohort is interpreted as having a strong positive 6.8>2.6; this value is also supported by the 95% confidence interval which indicates a strong association. These data can be interpreted as females older than 50 years of age being 6.8 times more likely to sustain a fracture than females between the ages of 36-50 years old.

Table 18 Stratified Analysis Output for the Association Between Fracture and Exposure by Female Cohort and Age: A Comparison of the Youngest and Intermediate Age Cohort

	Odds	Odds Ratio	95% Confidence Interval
18-35	0.1639	1.6147	0.5979-4.3606
36-50	0.2647		

Table 19 Stratified Analysis Output for the Association Between Fracture and Exposure by Female Cohort and Age: A Comparison of the Intermediate and Oldest Age Cohort

	Odds	Odds Ratio	95% Confidence Interval
35-50	0.2647	6.8472	2.6344-17.7972
51+	1.8125		

Table 20 Stratified Analysis Output for the Association Between Fracture and Exposure by Female Cohort and Age: A Comparison of the Youngest and Oldest Age Cohort

	Odds	Odds Ratio	95% Confidence Interval
18-35	0.1639	11.0563	4.471-27.3406
51+	1.81250		

In addition, Table 20 demonstrates a similar trend with an odds ratio of 11.1, indicating that there is a strong positive association between age and the outcome of a fracture (11.1>2.6). The 95% confidence interval exceeds well past the null value indicating a strong association between age and fracture outcome in the older female cohort. The odds ratio value demonstrates that females from the Kellis sample over the age of 50 are 11.1 time more likely to sustain a fracture that females between the ages of 18-35 in the same sample population. The stratification of data into sex and age specific groups allows for a more refined analysis of the trauma patterns throughout the Kellis subsample. It is evident that there is a strong correlation between increasing age and the likelihood of fracture within the female cohort.

6.4.6 Fracture, Male Cohort and Age

The sex-specific odds ratios comparing the likelihood of a fracture between the various male age cohorts indicate a significantly higher risk of fracture in older and intermediate age cohorts versus the younger age cohort. Table 21 summarizes the odds ratio values between the youngest and oldest male cohorts and demonstrates that older males were almost 6 times more likely to sustain a fracture than the younger male cohort (5.6>2.6), evidence of a strong positive association between older age and risk of fracture. The 95% confidence interval supports that this is a significant value as it does not contain unity (2.2-14.5).

Table 21 Stratified Analysis Output for the Association Between Fracture and Exposure by Male Cohort and Age: A Comparison of the Youngest and Intermediate Age Cohort

	Odds	Odds Ratio	95% Confidence Interval
18-35	0.2128	5.5813	2.1521-14.4747*
36-50	1.1875		

Table 22 Stratified Analysis Output for the Association Between Fracture and Exposure by Male Cohort and Age: A Comparison of the Intermediate and Oldest Age Cohort

	Odds	Odds Ratio	95% Confidence Interval
35-50	1.1875	3.9298	0.9563-16.1485
51+	4.6667		

Table 23 Stratified Analysis Output for the Association Between Fracture and Exposure by Male Cohort and Age: A Comparison of the Youngest and Oldest Age Cohort

	Odds	Odds Ratio	95% Confidence Interval
18-35	0.2128	21.9333	5.2933-90.8824*
51+	4.6667		

The odds ratio value for Table 22 suggests that there is a strong positive association (3.9>2.6) between the risk of fracture in the older male cohort in comparison to the intermediate age cohort. Relative to males in the intermediate age cohort, older males are nearly 4 times more likely to sustain a fracture. The 95% confidence interval is not significant as it contains unity (0.96-16.1). In Table 23, the odds ratio value demonstrates that males from the Kellis sample over the age of 50 are 21.9 times more likely to have sustained a fracture than males between the ages of 18-35 in the same sample population. This value suggests that there is a strong positive association between increasing age and the presence of one or more traumatic injuries in the skeleton. This is supported by the 95% confidence interval that indicates that this is a significant value that does not contain unity (5.3-90.9). Refining the male data into specific age cohorts allows for a more complete picture of the fracture patterning to be envisioned. Aggregating the sample allows for comparison between larger subsample groups however, these data must be interpreted with caution, as the statistical results obtained are indicative of discrete variations amongst both sexes and the various age cohorts.

6.5 Summary of Results

This chapter has demonstrated that the best method for interpreting fractures is to record the data by individual not by elements. The elemental data were provided for comparative purposes since most studies do not use the individual

as the comparative unit for various reasons (i.e., poor preservation). Both the prevalence and odds ratio calculations show the importance of stratifying the individual fracture data by both age and sex. This provides the best method of understanding fracture etiology within the specific context of the individual. Stratification can also be used to further explain similarities within the data and results that are deemed statistically non-significant, yet have an impact on the outcome. For example, both males and females in the oldest age cohort have the greatest risk of sustaining a fracture as they have had longer exposure to the risk. In this cohort, both sexes have similar risks of sustaining multiple fractures, yielding a non-significant odds ratio value. This is due to the cumulative nature of fractures in mortality samples. Although both experience the cumulative phenomenon, some fractures may have different etiologies that are masked by the higher frequency of multi-injured adults in the oldest age cohort. By comparing individuals from the male and female oldest age cohorts that have one or more fractures, its can be seen that the male individuals tend to represent injuries associated with accumulation whereas the females present injuries that are associated with bone density loss and osteoporosis. The patterning of fractures in the oldest female age cohort demonstrated that 8 of the 10 intertrochanteric injuries occurred in the later stages of life**.** These data are similar to current clinical outcomes, with 18% of hip and proximal femur injuries occurring in the 60 and over age cohort in contemporary populations (WHO 2003).

Some general statements of these trauma results are in order. Age and sex are important dimensions of the trauma pattern. Fracture risk in males is much greater than females before the 5th decade of life. Males have both higher rates of occupational and interpersonal (i.e., facial wounds) trauma. Throughout their lives, men are much more likely than women to suffer from all types of traumatic injuries, especially those associated with interpersonal violence (Walker 2001). In modern clinical literature, hospital emergency rooms in the United States report that the perpetrators and victims of modern assaults tend to be young men (Baker 1992; Walker 2001). Similar patterns are documented in

archaeological samples where young males have the highest frequency of trauma in sample populations (Judd 2002; Judd 2004; Brickley and Smith 2006) In the Kellis sample, it appears that males in their early years may be more prone to violence. Female trauma, in the early years in particular, may relate to birth trauma, which does not leave skeletal signs. With increasing age in the mid to late 40s, women are more prone to osteoporosis-related fractures and by the older cohort these traumas increase substantially. In the mud-brick houses today, as in the past, stairwells are relatively steep and do not have support railings. This physical structure could easily have been a potential source of falls and trauma in older women in ancient Kellis, as falls are the number one cause of hip fractures in contemporary populations (WHO 2003). Kellis males on the other hand did not experience trauma from bone demineralization but did have higher rates of trauma because they were age accumulative. Therefore the comparative data in males versus females in the older cohort may require adjusting. Stated alternatively the raw data greatly underestimates the risks of trauma in older females versus males. The trauma that resulted in 8 females having hip and/or femur fractures in the older cohort likely occurred during those years whereas the cumulative male trauma likely occurred gradually with age.

Further trends within the fracture data will be discussed in the final chapter. It can be seen from the results that the most representative values are derived from data stratification. Stratified analysis through the use of the odds ratio allowed for both the direction and strength of an association between two variables to be determined. This simple method proved effective for quantifying complex inter-relationships between various exposures leading to trauma in the Kellis population.

Chapter 6

7 Discussions and Conclusions

The final chapter of this thesis focuses on the discussion and interpretation of the results into a broader bioarchaeological context in section 6.1. The subsequent section, 6.2, outlines the research conclusions that were drawn from the completion of this study. The final section, 6.3, features possible research avenues for future studies of trauma in the Kellis sample.

7.1 Discussions

As noted in Chapter 1, trauma has been ubiquitous throughout human evolution. The substantive data on trauma in the bioarchaeological literature, though poorly standardized, clearly has shown that bone trauma increases with age and has a variant etiology between the sexes. This leads to the null hypothesis (H_0) investigated, ‘that there is no association of trauma with age and sex in the Kellis population’. This hypothesis has been rejected herein. The association of age with skeletal trauma is expected since bone remodeling would rarely eliminate bone traumas in adults, thus trauma that occurs in each age cohort is cumulative which increases the prevalence of trauma in older individuals. Of course the samples used in given studies must be large and representative of the population. In terms of sex, males and females experience different risks in virtually all environments such that males experience greater malintent (interpersonal and/or interpopulational) and occupational trauma than females. Whereas females, experience trauma related to the risks of daily life and their surrounding environment (i.e., steep stairwells, house hold tasks) especially older females who are at risk of bone trauma due to osteoporosis and an increased susceptibility to falls (WHO 2003). These male versus female traumas may be associated with a division of labour. Robb (1997) describes variation between male and female patterns of trauma in terms of the development of gender roles that prescribed violent behaviour for males and reinforced a sexual division of labour in which women were not expected to perform activities considered heavy

or dangerous. Although not universal, evidence from the modern Kellan population has shown that males and females participate in varying tasks and hold different roles in the community (Personal communication Dr. J.E. Molto 2016).

Lovell (1997) suggested two interrelated levels in the causation of trauma: proximate and ultimate. Proximate mechanisms of injury involve determining whether a fracture is the result of direct or indirect trauma or if the injury is secondary to pathology (e.g., bone weakened by a tumour). The ultimate mechanism of injury considers the influence of both intrinsic constitutional factors like age and sex and the extrinsic environmental and/or sociocultural factors. As the causes of trauma are population specific, it is important to recognize that the etiology can vary according to environmental or extrinsic factors (i.e., ultimate factors). It is thus worthwhile to overview the information available at Kellis in terms of assisting with the ultimate causation of trauma. The occupants at Kellis were involved in agricultural pursuits that are mirrored by today's Dakhleh Oasis dwellers. Though there is some modern mechanization (e.g., tractors, cars etc.) in today's population, the Dakhlens share similarities between their ancient ancestors including their subsistence patterns, occupational hazards and climate.

Daily, the members of the Dakhleh Oasis Project have witnessed a lifestyle that provides a glimpse of the past in terms of the climate, subsistence, village structure and the occupations defined along the traditional gender division of labour. The men at Kellis, like today's Oasis dwellers, prepared and controlled the irrigation in the fields, harvested the many crops, tended the animal husbandry, constructed the mud-brick homes and were involved with trade within and beyond the Oasis (Molto 2001; 2002a). Females dominate the domestic program (gathering foods from their nearby gardens, food preparation, cooking, child rearing etc.) (Molto 2001; 2002a). According to McCurdy (2000) and Roberts and Manchester (2005) agriculture has been identified as one of the most dangerous occupations in past and present. The main difference between past and present populations is, of course, the fact modern populations are

mechanized, but the latter authors note that tending and utilizing (e.g., riding, plowing etc.) livestock and harvesting crops (e.g., grains, fruit, vegetables) results in trauma risks, particularly falls. It is worthwhile to note that falls are the predominant sources of farm related injuries (Armelagos and Cohen 1984). As farming in Kellis was primarily a male pursuit (Molto 2011; 2012a), females had a greater exposure to dangers within the village and home. As previously noted, the mud-brick home of Kellis sported steep stairwells with no supporting handrails. Although seemingly harmless, to an older woman with bone demineralization and a subsequent increased risk of fracture, these stairs may be a potential source of a fall, resulting in a hip and/or femoral neck fracture.

The malintent trauma previously noted for the Kellis sample was probably a product of interpersonal conflicts, particularly in the males. As the Dakhleh Oasis was relatively isolated during the Roman occupation, warfare and intra-population violence are not believed to be large contributors to the malintent trauma in the Kellis population. While there were instances of unhealed sharp-force trauma to the ribs and vertebrae in two young adult males, most of the trauma involved the maxo-facial region of the skull, with several depression fractures on various cranial vaults being observed. The facial trauma involved several healed fractures of the nasal region, interpreted as due to fisticuffs. There were no facial fractures in the Kellis females, which shows that malintent trauma was predominantly found in males. The depression fractures in the female crania were smaller and much fewer in number. Overall the malintent trauma at Kellis is very low. For example, Molto (2015) in his analysis of malintent trauma in the Las Palmas population of the Cape region of the Baja peninsula found over 62% of males and 36% of females had traumatic wounds, mostly to the skull. In addition, in a skeletal collection from western Tennessee, 20.4% of individuals showed evidence of perimortem violence (Walker 2001). Considering that the Kellis subsample showed evidence of trauma in less than 4% of individuals, the overall prevalence of trauma within the population is low.

In this thesis trauma was reported both by skeletal element and by individual. Both methods provide useful constructs in understanding trauma risk, although the former is more problematic. These elemental data are presented for use in comparative studies, as the majority of bioarchaeological research report trauma by element only, particularly skulls. Clearly reporting trauma risk by individual is more meaningful as it the individual who interacts with their environment. It also facilitates better control of key constitutional variables (i.e., age and sex), and the investigation of the multiple traumas when occurring on different skeletal elements. For example, many studies report only cranial trauma (Jurmain and Bellifemine 1997; Agnew et al., 2015) thus we do not know whether infracranial trauma was present in these skeletons. As noted, cranial trauma is often thought to reflect interpersonal violence (Walker 2001; Molto 2015) the interpretation of skull trauma could provide misleading interpretations at the population level.

The aging and sexing of the Kellis sample was done in blind. In this sample, sex determination was very accurate and precise (Molto 2001), and while age was determined using multiple aging methods, it is still problematic for older adults. Dividing the sample into three age cohorts (18-35, 36-50 and 51+) allowed some control over the age variable. As well, the odds ratio for testing prevalence of trauma was used as this statistic has the advantage of determining risk by the strength of association (e.g., X has a 10 fold risk of trauma than Y) not just by statistical significance. Moreover, the odds ratios can indicate statistical significance by utilizing the 95% confidence interval. A confidence interval may include unity (= non significance) but the actual value can indicate that the two variables being compared carry very different risks (e.g., A is 4 times more likely than B to experience a given trauma despite the small odds ratio).

In terms of causality, the prevalence of skeletal trauma was organized into four broad categories: malintent, occupational, accidental and other (e.g., birth trauma). Obviously some interpretive problems arise in placing individual traumas into these categories, but with larger sample sizes herein some of the

interpretive errors may be minimized. Still, there are many confounding variables in the interpretation of trauma causality that require consideration. First, is the smoothing effect: a constant rate of trauma that occurs throughout the population. Waldron (1994) describes the smoothing effect as a period of relative frequencies that do not drop or peak but rather stay relatively the same due to the accumulation of samples over extended periods of time. As the Kellis sample spans 300 years the prevalence data do not necessarily reflect the fluctuations in trauma prevalence temporally. This may not be as problematic for the Kellis sample as the population has had a similar subsistence patterns and geographical location for millennia. Secondly, most traumas to the human body do not leave skeletal evidence. This greatly underestimates the true prevalence of trauma in past populations. Thirdly, all skeletal samples are by definition cross-sectional (Waldron 2008), which can result is some interpretive problems. For example, the results show that females in the middle cohort (36-50) did not experience any head trauma though in the youngest cohort cranial trauma was present. This result is seen as stochastic due to the cross-sectional nature of the sample. Clearly the risks of having head trauma should be higher in the older cohorts, as the prevalence of a mortality sample is cumulative. A fourth confounding variable is the problem of determining when traumas occurred during an individual's lifetime and in the event of multiple traumas, if they occurred during a single event (e.g., a major fall) or multiple events. Only cases where an individual has well-healed lesions, plus perimortem traumas, can we definitely indicate that there were separate events.

The analysis of the Kellis sample has shown the importance of stratifying trauma data by age and sex. For example, if data were only organized by sex (males versus females without considering age) the overall fracture risk in the Kellis population was virtually the same between the sexes (OR of 1.3). This result was not significant. Both sexes showed that the ribs were the most common element affected by trauma. Yet when the prevalence data were organized by sex and age juxtaposed, it is clear that the similarities in overall prevalence are varying in terms of ultimate factors. The similar prevalence rates

in trauma between males and females when divided by age show major differences in trauma etiology, despite both sexes showing increasing trauma prevalence with age. For one, the male trauma pattern with age is more gradual than that of the females. Male trauma in the earlier age cohorts was much greater than females. Females in the oldest cohort had considerably more traumas related to osteoporosis, primarily because of the interaction of bone demineralization and their domestic environments (e.g., stairs), which increased their risk of bone fracture in the areas associated with osteoporosis syndrome (i.e., hips, vertebrae, ribs, and distal forearm bones). The fact that ribs were the most commonly affected bone type in both sexes is a moot point when it was shown that the males in the earlier age cohorts had greater risk of rib fractures due to occupational and/or interpersonal factors, whereas most of the rib trauma in the females occurred in oldest cohort due to osteoporosis. It is well known that falls are a major factor in the etiology of all rib fractures (Brickley 2006) but the falls between the sexes have to be interpreted in light of the different constitutional (i.e., hormonal) and occupational risks.

The pattern of skull trauma was also different in the males and females as males had significantly higher rates, which included facial trauma that was totally absent in the females. The underlying cause of facial (skull) trauma in males was due to interpersonal disagreements. In some cases the males showed unhealed sharp force trauma to both the ribs and the vertebrae presumably the result of interpersonal violence. No female exhibited sharp force trauma. Blunt force trauma to the cranium was present in both sexes but was most likely due to interpersonal violence in the males, although some cases may have reflected occupational and or accidental causes. Also some cases of blunt force trauma in female crania could reflect domestic violence, although in individual cases it is difficult to ascertain the proximate cause. It is noteworthy, however, that there is a least one case of infant/childhood trauma that reflects domestic violence in the Kellis population (Wheeler et al., 2013).

The Kellis data also showed that multiple fractures to the pelvic area (intertrochanteric, hip, and sacral), associated with osteoporosis, occurred only in the older females. The prevalence of 18% in postmenopausal women was virtually identical to the data reported by the WHO (2003) for modern western populations. Moreover, at least half (5/8) of the females with hip fractures died shortly after the event and of the 8 with hip fractures all but 1 had other osteoporosis related fractures. This constitutional (bone demineralization) factor obviously resulted in the high prevalence of females with multiple fractures in the oldest age cohort. No male had hip fractures that occurred in the oldest cohort, though, at least two sustained hip fractures in the younger cohorts, which were probably related to occupation, such as falls from donkeys, or consequent to roof collapses. The latter is found today and there are two Kellis individuals (an adult and a child) adjacent to each other in the cemetery with multiple and widespread unhealed lesions that could possibly reflect trauma from a collapsing roof. The contextual evidence as well as the extent of these individual's injuries are indicative of a singular event.

The interpretive results discussed in this chapter highlight the importance of stratifying data to create the most accurate representation of trauma patterns in ancient Kellis. If the data were not organized by age and sex then our understanding of the ecology of trauma in this population would be compromised and indeed incorrect. To illustrate, consider the similarities between the sexes. Males and females have insignificant differences in overall trauma, both show that overall trauma increases with age with both showing the highest prevalence in the older adults; ribs were the most common element with fractures, and the prevalence of multiple traumas were similar in males and females. However, these similarities are misleading because the etiologies of the fractures are very different for males versus females. When delineated by age and sex fracture risk in males is much greater than females before the 5th decade of life. Males have significantly higher rates of occupational and interpersonal (e.g., facial wounds) trauma. Males in the younger cohorts likely experienced multiple traumas due to farming activities whereas the majority of multiple fractures in females occurred

in the oldest cohort due to osteoporosis. Males, particularly in their early adult years, may also have been more prone to violence as a means of obtaining success, a phenomenon that can be classified as ‘testosterone violence’. The limited prevalence of trauma in young and early adult females relative to males is noteworthy and in general the risk of fractures for females in the two earliest cohorts is significantly lower than the males. With increasing age in the mid to late 40s women are more prone to fractures due to bone demineralization. A fall, which is the key cause of fractures in both men and women, particularly in the ribs, would not result in major fractures in young adult females but when they reach the menopausal years the same falls result in a number of major fractures. Though older (51+) female and male cohorts both have the highest prevalence of fracture, it is clear that the majority of fractures in females actually occurred in the oldest cohort whereas the male data represents an accumulation of trauma over the adult years. Males that sustained facial (i.e., broken nose) and other traumas in the earlier adult years would show these lesions if they died in their 50s or 60s. Older females with osteoporosis-related fractures in the hips, ribs, distal forearms and vertebrae, the so-called osteoporosis fracture syndrome, would necessarily endure these traumas in the oldest cohort. Noteworthy, is that there is no evidence of osteoporosis-related traumas in the older males, which is expected as Type I osteoporosis primarily affects females (WHO 2003).

A study of the bone quality and quantity in relation to the bone fractures at Kellis has been conducted and corroborates the findings of this thesis. Teeter (2015) conducted a blind study of the osteo-volumetric analysis of the 1st metatarsal using human remains from the Kellis cemeteries located in the Dakhleh Oasis, Egypt (50-450 AD). Males and females were found to have different osteo-volumetric density patterns and an inverse relationship between age and the estimated bone mineral densities (BMD) for females was far more pronounced than what is seen in males from the same population. The MT1s from 8 post-menopausal females (the same individuals identified in this study as having osteoporosis fracture syndrome) yielded BMD results consistent with the WHO recommendation for diagnosing osteoporosis, <-2.5 standard deviations

from the '*healthy*' adult female bone density mean (Teeter et al.,2015). These results corroborate the earlier assumption that osteoporosis was the main contributor to increasing fracture risks in post-menopausal females. Germane to this information is that no females under the age of 40 presented evidence of low bone density or osteoporosis-related fractures (ibid). As noted, males did not experience the same demineralization rate as females in the Kellis sample population, which would explain a decreased susceptibility to radial, hip and vertebral fractures when compared to females.

The relationship between bone mineral density and the outcome of an osteoporosis-related injury can be explained in terms of an underlying pathology leading to increased bone fragility and susceptibility to unintentional falls. Given the rugged terrain of the Oasis in addition to the multi-level homes that individuals lived in during the Roman occupation of Kellis, it is not difficult to visualize how everyday tasks such as climbing the stairs could have resulted in traumatic and perhaps fatal accidents in females during the later decades of life.

7.2 Conclusions

This study has utilized data from an ancient Roman period population in the Dakhleh Oasis that has an enormous amount of bioarchaeological, historical and paleo-ecological data to assist in reconstructing the environment that the ancient Kellans inhabited. The skeletons from the Kellis population were single interments that had ideal preservation and representation due to hyperarid conditions. Few studies have this luxury. From this research on trauma, a number of conclusions can be advanced.

1. When possible, all research on trauma should use the individual as the unit of investigation as skeletal elements by themselves lead to a limited understanding of trauma in past societies.
2. All future studies, when possible, should organize trauma data by age and sex; amalgamating comparative data by sex without regard to age, would result in serious interpretive errors (in this study Type II errors).

3. Understanding the paleo-ecology of all populations is necessary in order to place the trauma and other paleoepidemiological data in context. With these data we had the luxury of both a living population and an environment similar to that of the ancients Kellans and understanding the risks presented to them in this hostile desert.
4. Quantitative analyses of trauma should use the odds ratio, which is commonly utilized in modern clinical and epidemiological studies. However, there are many other statistical tests that can be used such as multiple regression and person years constructs-the key to quantitative analyses rests with the overall sample sizes. When samples have poor, or unknown provenience, coupled with a small size, the results would be very speculative.

7.3 Future Research

Future research on this sample should include comparative studies with other populations. However, as noted, most research report data by element, not by individual, which makes hypothesis testing extremely problematic. For example, the excellent recent dissertation by Glencross (2002) though sophisticated statistically, only reported data on long bones, whereas many others only report data by skulls (Walker 1989; Jurmain and Bellifemine 1997; Jurmain et al., 2009). These studies often do not, or cannot, control the age variable very systematically, which was done herein using multiple methods.

Future studies must make greater use of clinical and epidemiological data. The clinical data help us to understand the etiology of fracture patterns. For example, the cases of humeral varus deformity noted herein are most likely due to birthing trauma and possibly the use of midwives (Molto 2000). Using the paleopathology literature alone would have resulted in a misdiagnosis of mucopolysaccrodosis (Molto 2000; Ortner 2000). The clinical literature is best suited to analyzing individual cases of trauma before the population data can be amassed. Another potential source for fracture interpretations would be the kinesiology data on trauma in sports. In university and professional sports all

injuries are examined thoroughly (e.g., x-rays etc) which provides a large database to examine the behaviours causing fractures. As noted, the fracture data in paleoepidemiology greatly underestimates the true prevalence of the behavioural events leading to trauma because bone is not commonly affected. For example, hockey players often get hit in the ankles by slap shots – but maybe it takes 50 events (the shot in the ankle) to produce 1 fracture. Too, if it takes 25 fights to produce a broken nose, then comparing the fracture prevalence in two samples could easily result in a Type 2 error because the fracture rates were not adjusted for the behavioural data. It is important to emphasize that it is the behaviour causing the trauma that we are most interested in. Such data could prove useful for predicting the behaviours behind the events rather than the fracture prevalence itself. Another potential source of data to help interpret fracture prevalence would be collecting information on the modern agrarian Dakhleh population. The Dakhleh Oasis Project has a physician, Dr. Peter Sheldrick, who is well-connected with the Dakhleh population, including local physicians, and has the confidence of the local population. Amassing such data on the modern Dakhlans, a population that is gradually modernizing, would provide the litmus test for the interpretations of trauma in the ancient inhabitants of the Oasis.

Finally, it is important to note the emergence of a new investigative approach within the discipline known as the ‘bioarchaeology of care’ (Tilley 2012) which, can be used to better understand the ‘lived human experience’ by inferring past life ways from human remains that exhibited some form of pathology. Recently, I applied this technique in a research paper focusing on an older Kellis female (K2 191) who had survived a major hip fracture. This individual suffered from an intertrochanteric fracture that while healing developed into a pseudoarthropy, which allowed for mobility. The extensive healing present at the injury site indicates that this individual lived for several years after the fracture event (Figure 9). Even today hip fractures in postmenopausal females are a major source of morbidity and mortality with survival rates dependent on immediate surgical intervention following the event (Nevitt et al., 2005). The fact

that this Kellis female was able to survive for what appears to be a considerable amount of time (just how long is indeterminant) may be testimony for care in the Christian Kellis community. Focusing on the level of direct care (i.e., was the injured individual supplied with appropriate necessitates such as food, water and medical treatment) and indirect care (who cared for this individual) provides insight into the plight of people who like those in present day, had to deal with diseases and traumas that challenge quality of life and overall life expectancy (Agarwal and Glencross 2011). Integrating this approach within the realm of paleoepidemiological statistics should be a major focus of our discipline in future. Such a focus will bring modern clinical practitioners and paleoepidemiologists even closer, thus fulfilling the ultimate goal of interdisciplinary work in paleopathology.

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