

Chapter 1

INTRODUCTION TO BIOARCHAEOLOGY: HISTORY TO PRESENT

1.1. INTRODUCTION TO BIOARCHAEOLOGY

Bioarchaeology is the study of human skeletal remains from archaeological settings to aid in reconstructing the biological and cultural pasts of populations. This book provides an overview of bioarchaeological theory, methods, and applications with an emphasis on the latest literature published in the top journals. Bioarchaeology is one of the lesser-known fields of physical anthropology, and yet it is one of the most researched topics in physical anthropology. In 2006-2007, a quarter of all the articles published in the *American Journal of Physical Anthropology* (the top peer-reviewed physical anthropology journal) were on studies of human skeletal remains. The next most published theme of population genetics lagged far behind, accounting for only around 15% of all published articles. Furthermore, bioarchaeology has gained in popularity around the world and there are a growing number of bioarchaeological studies coming from European, Asian, and South American anthropologists. Finally, introductory courses in physical anthropology are starting to include bioarchaeology as a topic of importance (see *Our Origins* by Clark S. Larsen) and thus, a new wave of student interest in bioarchaeology may arise. Bioarchaeology is arguably physical anthropology's most important field.

1.2. HISTORY OF BIOARCHAEOLOGY

An extensive history of bioarchaeology has been published in the edited volume by Jane Buikstra and Lane Beck (2006). This section will highlight a few of their findings, especially with regard to reconstructing activity patterns (which are the physical endeavors people engaged in) and understanding pathologies (i.e., diseases). Before delving into these topics of activity pattern and pathology reconstructions, I think that it is important to point out that bioarchaeology began in the 1800s and, as such, is a relatively new field. Early anthropologists who studied skeletal remains, such as Aleš Hrdlička and Ernest A. Hooton, were generalists who studied everything from Native American origins to case studies (which

are studies that involve a single skeleton or a very small sample size and are descriptive) of diseases. Hrdlička was trained in the medical field and as a consequence was very descriptive and relished case studies of individuals. He also spent a great deal of time trying to understand human variation and the origins of Native Americans. Hooton was more embedded in the social sciences and came from a Classics approach; therefore, Hooton engaged in the act of intertwining the research of archaeology and skeletal remains found at sites, such as the Pecos agricultural Amerind (American Indian) site in New Mexico in 1930. Hooton's work on the Pecos Amerind site was problem oriented and probed into questions regarding demography (best defined as the distribution of age and sex of populations) and taphonomy (also known as the laws of burial, describing how remains become buried and what happens to the remains from the time they are buried until their discovery). He was also interested in population health as opposed to the more descriptive case studies of an individual's health. Thus, even though most early anthropological works are described as being purely descriptive in nature, Hooton and Hrdlička went beyond description to attempt to answer questions about the past. (Buikstra and Beck, 2006)

With regard to activity pattern reconstructions, bioarchaeology had modest beginnings. As summarized by Pearson and Buikstra (2006) and Jurmain (1999), J. Lawrence Angel was likely the most productive anthropologist to work on reconstructing activity patterns of past populations. In 1952, Angel produced a description of three skeletal remains that were dated as being 9000 years old from Iran that included likely the first use of bone form and muscle insertion information to reconstruct activities, such as pulling fishing nets (Pearson and Buikstra, 2006). On California remains, Angel talked of the torsion, or twist, of the tibia in cases and related this torsion to running on tough terrain. Angel started a bioarchaeological revolution to use skeletal features (everything from muscle markers to arthritis) to bring the movement to bones (Pearson and Buikstra, 2006). Angel's work was heavily influenced by anatomists who were attempting to understand human biology; for example, German anatomist Julius Wolff tried to understand trabecular (spongy) bone orientation through muscle use and strains placed on bones as early as 1892. Wolff's work will be discussed in the next chapter. Angel was also influenced by Rudolf Virchow, another German anatomist. Virchow's expertise was in pathology (disease) and he demonstrated how the human body's plasticity responded to external forces and strains (Pearson and Buikstra, 2006). This view of the body as a dynamic entity led anthropologists to produce fewer typological (classification) studies and start attempting activity pattern reconstructions.

Another section of bioarchaeology that has a rich history is that of the study of pathologies. Paleopathology, which is the study of disease in past populations, is one of the most popular research topics in anthropology currently. Paleopathology employs knowledge from medicine, dentistry, and anthropology. It began as a pastime for physicians during the 20th Century (Cook and Powell, 2006). For instance, Sir Marc Armand Ruffer, a British physician who worked on Egyptian mummies, is often thought of as the first paleopathologist. Roy L. Moodie, an anatomist, published some of the first volumes on paleopathology. One of his early publications was titled *Paleopathology: An Introduction to the Study of Ancient Evidences of Diseases* (1923). Most of these early works on paleopathology were descriptive, which is not surprising considering the researchers' medical training and the likelihood that some pathologies were found in single individuals only. It was not until the 1960s that paleopathology took on a more problem-oriented approach (Cook and Powell, 2006). As an example, anthropologist Saul Jarcho wrote an article that was published

in *Science* in 1965 that brought to people's attention the need for within-field and interdisciplinary collaboration, and the necessity for more than just descriptions of the pathologies (Cook and Powell, 2006). Nonetheless, paleopathology remains more descriptive than other aspects of bioarchaeology and struggles to place diseases into a greater contextual framework.

There are many other aspects of bioarchaeology and the history of bioarchaeology that can be covered, such as the study of dentition, the beginnings of genetic evidence, and the beginnings of isotopic analyses. Bioarchaeology is a field with many specialties; specialties, however, are relatively recent developments in this field of study. Thus, to cover the histories of all the specialties is a book in and of itself, and Buikstra and Beck's (2006) book does just that superbly. Let us move on by examining research trends in bioarchaeology prior to probing into the latest findings.

1.3. RESEARCH TRENDS IN BIOARCHAEOLOGY

Analyses of published literature has highlighted trends in Bioarchaeology, both in the USA and abroad. In 2008, anthropologists Samantha Hens and Kanya Godde examined publication trends in the *American Journal of Physical Anthropology* in an attempt to determine whether the call for more analytical research by Lovejoy and coworkers (1982) and Armelagos and coworkers (1982) has been heeded. Hens and Godde found that, although the shift from descriptive studies to analytical studies (which includes having a hypothesis, a theoretical base, and advanced statistics) may not have been as complete as anthropologists have claimed, over the last two and a half decades researchers have attempted analytical research more often than previously. In the last ten years, analytical research has increased dramatically, especially in topics on age, sex, stature, and demography. Descriptive studies, however, still prevail in the United Kingdom (Mays, 2008), which may be in part a remnant of the medical background that anthropologists in the United Kingdom were trained in during the 1960s through 1990s. Furthermore, pathology research is still heavily descriptive (Mays, 2008; Hens and Godde, 2008; Stojanowski and Buikstra, 2005). Some of the descriptive research is important in cases where new characteristics arise in skeletal material that may aid others in identifying diseases. Description also may be useful when new methods are being employed and the theoretical framework for the data has not been laid down. Nonetheless, descriptive studies have far less impact on the field, are published more often by novices, and are cited less frequently (Stojanowski and Buikstra, 2005). Thus, the majority of studies reviewed in this text are analytical rather than descriptive.

Another interesting aspect of bioarchaeology research has been the increase in use of traits to identify diseases, environmental stresses, and population health. Case studies that focus on single individuals have declined in the last few years, (Mays, 2008) as have studies on single skeletal health indicators. Anthropologists are recording more indicators of health and disease, genetics, and activity than previously and are often using sample sizes large enough for statistical analyses. Finally, an important trend in research has been the rise in technology as indicated by an increase in genetic research (e.g., ancient DNA) and isotopic studies, which can aid in understanding diet and weaning patterns. This trend is particularly strong in the United Kingdom and Germany (Mays, 2008). Interestingly, some of these

research methods are destructive and, thus, may face difficulty being approved in the USA where ethical issues surrounding prehistoric Amerind remains are especially sensitive.

In conclusion, bioarchaeology is a relatively young field that has grown immensely, but is still feeling its growing pains. To better understand bones and human biology, many anthropologists have turned to medicine and sports literature, which is where information on bone biology and theories of bone remodeling arise that help us better understand the past.

Key Terms

Bioarchaeology
Paleopathology
Demography
Case Studies

Chapter Questions

- 1) Who were the key researchers in the early days of bioarchaeology and what were their contributions?
- 2) What is the difference between bioarchaeology and paleopathology?
- 3) What research trends have appeared in bioarchaeology?

Chapter 2

BONE BIOLOGY AND HUMAN OSTEOLOGY: BASICS TO UNDERSTANDING OSTEOLOGICAL RESEARCH

Anthropologists examining skeletal material from archaeological sites use skeletal evidence to reconstruct past lives with an emphasis on referencing medical and sports literature to understand the characteristics visible on bone. Thus, understanding bone biology is essential in the study of bioarchaeology.

Bone functions include the protection of organs and the support of soft tissue, such as skin; providing a surface for muscles and connective tissues, such as tendons and ligaments, to attach onto; and acting as a lever system that is intrinsically involved in all our movements (White and Folken, 1991). The skeletal system also stores fat and calcium, and provides locations for the production of blood cells. Bone tissue is a dynamic material that changes with the growth of an individual and interacts with stresses placed on it by mechanical loading (White and Folken, 1991). We will return to bone remodeling later in the text after a brief description of bone biology.

Bone is a strong, hard substance due to its combination of organic and inorganic components, which consist mainly of collagen and minerals (such as calcium). Bone responds to stresses, which are internal forces on bone, with various levels of stiffness relying on the rate and duration of the stress applied to it (Hamill and Knutzen, 1995). Collagen provides bone with ductile properties that allows the bone to warp or deform rather than break when stressed, whereas mineral constituents of bone account for brittleness and provide strength to the skeletal system. This combination of deformability and brittleness is especially important when anthropologists consider bone form in regard to past activity patterns.

At the macroscopic level, the skeletal system of an adult consists of two basic types: cortical (compact) and trabecular (spongy) bone (Figure 2.1). Cortical bone is solid and dense; it makes up the shafts of long bones and the other surfaces of all other bones (Bass, 1987). In skeletal remains found in the archaeological record, cortical bone is the most abundant since its denseness aids in its preservation (Bass, 1987; Swartz, 1996). On the other hand, trabecular bone is porous and lightweight, which reduces the chance of its preservation (White and Folken, 1991). Trabecular bone can be found at the end of long bones, such as at the femoral head. Blood-forming tissue lies in the areas of trabecular bone in the growing skeleton and is then replaced by yellow marrow in the medullary canals of long bones.

Epiphyses are the end of long bones, which fuse once growth has ceased, and metaphyses are also known as shafts (White and Folken, 1991).

During life, bone is covered with a tissue called the periosteum, which aids in nourishing bones but is not found in the bioarchaeological remains. The inner surface of bone is lined with the endosteum. Both the periosteum and endosteum are bone-forming (osteogenic) tissues where cells that form bone material are plentiful in young individuals, and are still active and present throughout adulthood (White and Folken, 1991). These tissues are especially active during trauma, such as when a bone is broken and new bone is required for healing.

On the microscopic or histological level, bone is better understood by breaking it down to immature and mature types. Immature bone, which occurs throughout life and is found in very young individuals or soon after trauma has occurred, is disorganized and is replaced by mature bone. Mature bone (also known as lamellar bone) is arranged in a canal system called the Haversian system (Hamill and Knutzen, 1995) (Figure 2.2). The Haversian system consists of a central canal that is surrounded by lamellae (thin sheets), lacunae (small cavities), and canaliculi (small canals) (Tortora, 1995). The central canals run through bone longitudinally and are surrounded by rings of calcified matrix that are called lamellae (Tortora, 1995). Between these hard sheets of lamellae are spaces called lacunae that contain mature bone cells, and radiating from these lacunae are minute canals (or canaliculi) that are filled with fluid (White and Folken, 1991). Canaliculi connect lacunae with each other and with the central canals. This Haversian network provides routes for nutrients and oxygen to allow for bone to stay alive and dynamic.

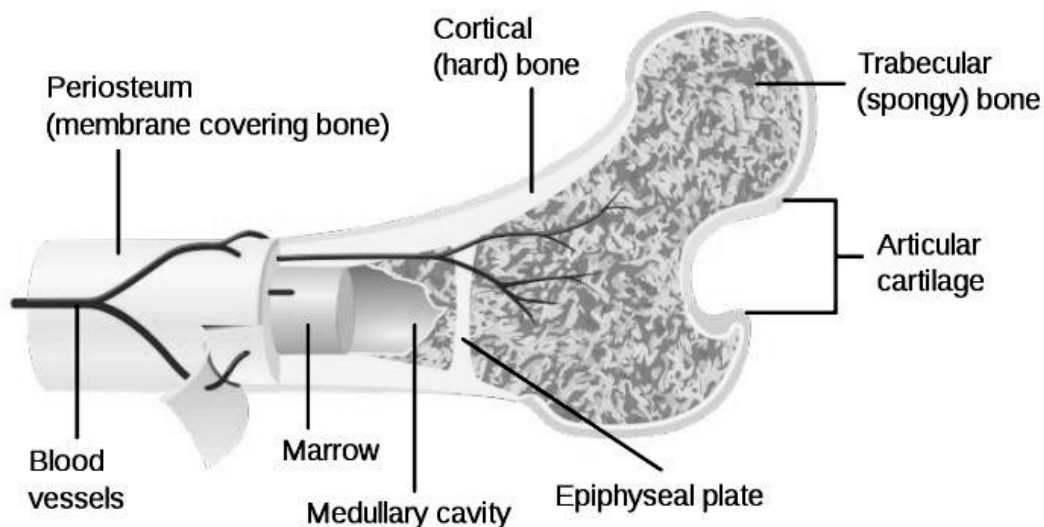


Figure 2.1. Macroscopic view of bone biology. Taken from Pbroks13 on Wikipedia Commons.

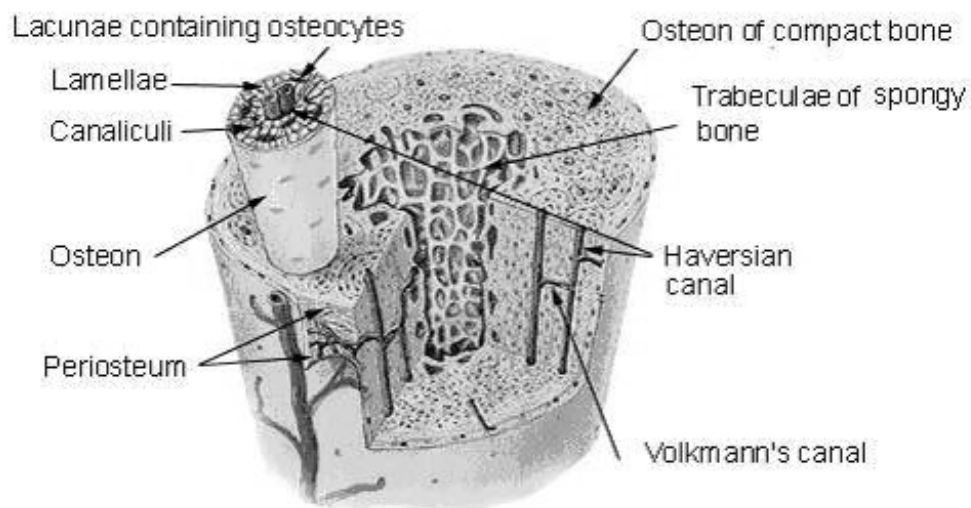
Compact Bone & Spongy (Cancellous Bone)

Figure 2.2. Microscopic view of the Haversian system. Taken from U.S. National Cancer Institute's Surveillance, Epidemiology and End Results (SEER) Program. (<http://training.seer.cancer.gov/index.html>).

With this brief introduction to bone biology, we can now move on to understand how anthropologists use bone to look at past activities, trauma, and diseases.

Key Terms

Cortical Bone
Collagen
Endosteum
Osteon
Periosteum
Haversian System
Trabecular Bone

Chapter Questions

- 1) What are the functions of bone?
- 2) What are some of the properties of bone that make it flexible and what are some that make it hard?
- 3) What are the differences between trabecular and cortical bone?
- 4) How do mature bone and immature bone differ?

Chapter 3

RECONSTRUCTING ACTIVITY PATTERNS: MAKING DEAD PEOPLE MOVE

3.1. INTRODUCTION TO RECONSTRUCTING ACTIVITY PATTERNS

One of the main research trends bioarchaeologists engage in is the reconstruction of past activity patterns. Anthropologists have been trying to determine the things people did who lived in prehistory. For example, they want to know whether males and females engaged in different activities (i.e., was there always a sexual division of labor or is this something new). They are also interested in determining how people's lives changed with the advent and adoption of agriculture, with the invention of various tools, and with the contact of other people (i.e., when Europeans made contact with Native Americans). In order to reconstruct activities, such as hunting, long-distance traveling, and food preparation, anthropologists have utilized a variety of methods. These methods can most easily be broken down into those that invoke the theoretical basis of Wolff's Law and bone remodeling, such as cross-sections, muscle markers, and asymmetry, and methods that look at bone deterioration (or wear and tear), such as osteoarthritis and vertebral stress fractures. Any trait that is examined has complications and confounds, which will be addressed in the following sections. However, there is promising data throughout the literature that suggests activity reconstruction can be accurate when conducted with care in respect to controlling for biological confounds.

3.2. WOLFF'S LAW AND BONE REMODELING

Newton's Second Law of Motion states that when a force is applied to an object, the object will accelerate. If, however, restraints are placed on the object that prevent it from moving, then the movement will occur within the object in the form of deformation to accommodate the force. All biological tissues deform to an extent when forces are applied, even if motion occurs. Thus, when a limb muscle places force on a bone, the limb will move (and perhaps even move the entire organism), but some deformation will also occur due to restraints. Mineralized tissues remodel in order to reinforce themselves to prevent breaking from these deformations and this is where bone remodeling comes in.

Two types of cells are responsible for bone remodeling and healing: osteoclasts and osteoblasts (White and Folken, 1991). Osteoclasts develop from white blood cells and resorb (or take away) bone. Osteoblasts, which make pre-bone tissue known as osteoids, are responsible for new bone material. Osteoid tissue is un-calcified and not hard, leading us to the final step in bone repair and remodeling: calcification. In order for calcification to occur, certain minerals and vitamins are essential. For example, calcium, which is a mineral found mainly in dairy products, is needed for bone development and maintenance. About ninety percent of calcium is stored in bone, where it can be reabsorbed by blood and tissue. Fluoride is another mineral important for bones, especially for growth and protection against demineralization of bone. Fluoride is added to toothpaste and in our water to prevent cavities, which is the demineralization of enamel. Unlike bones, teeth do not remodel, making this protection essential to our health. Finally, vitamin D, which is found in eggs, liver, and fish, and is synthesized by the body with exposure to ultraviolet radiation, regulates calcium absorption. Without these vitamins and minerals, bone health can be severely hampered even if exercise is practiced (Tortora, 1995).

Bones experience external and muscular forces throughout an individual's life that the bone must respond to in order to prevent breakage. Muscle use is important in remodeling bones and maintaining strength because muscle usage places the stress on bones necessary to activate osteoblasts (Hamill and Knutzen, 1995). Bone, in other words, thins with loss of activity and thickens with increase of activity. Osteoblasts, which are responsible for making and depositing bone material, respond to stress by making un-calcified, collagen-rich, pre-bone tissue. The final step in bone deposition is calcification, which leads to the synthesis of true bone; it occurs as the inorganic components of bone are deposited in the pre-bone tissue (White and Folken, 1991).

Bone remodeling has long been thought to occur at particular locations due to specific muscle use. The first person to provide evidence for this was German anatomist Julius Wolff in 1892, whose statement on it became known as Wolff's Law. Wolff's Law states that:

"Every change in the form and function of a bone or the function alone, results in definitive changes in the internal architecture of the bone and equally definitive changes in the external architecture in accordance to mathematical laws."

According to Wolff's Law, cortical and trabecular bone interact dynamically with specific environmental (which in this case means non-genetic) forces. When such a force is applied to a bone, it causes the bone to deform (or experience strain) which induces local bone formation by osteoblasts (remember these are bone-forming cells) (Amtmann, 1968; Chamay and Tschantz, 1972; Woo et al., 1981). Localized bone remodeling, which is achieved by the addition of new bone by osteoblasts and bone resorption by osteoclast cells, is adaptive since it reduces the threat of bone breakage. The next sections will address how anthropologists use Wolff's Law as a theoretical basis for examining cross-sections of bone to reconstruct the past activity patterns.

3.3. CROSS-SECTIONAL DATA

As mentioned above, bone tissue is a dynamic material that interacts with stresses placed on it by mechanical loading. The result of bone remodeling mentioned above is altered bone morphology, which can be measured by examining cross-sections of bone. Bone repairs itself and alters its configuration in response to mechanical demands (Hamill and Knutzen, 1995). Environments place varying demands on the bones of individuals; thus, determining how environments affect bones can aid in understanding peoples' past lives in different areas. And although genetic factors influence the final form of bone, later bone development is affected by non-genetic factors, such as remodeling after bone breakage and remodeling in response to specific stresses and strains to prevent bone breakage, as mentioned above (Wolff, 1892). Mineralized tissues remodel to reinforce themselves to prevent breaking. Forces, which are referred to as loads applied to solid objects, cause bone deformation known as strain. Forces are often caused by the mechanical environment, such as exercise of muscles. For example, the many muscles attached to the humerus apply force to the bone to create motion. The harder these muscles work, the more force is applied. The physical environment may also influence the amount of work necessary to perform certain tasks, such as walking on treacherous terrain compared to flat terrain.

Activities causing strains on bone lead to internal stresses that can break a bone if remodeling has not occurred (Figure 3.1). Throughout life, loads repeatedly placed on bone may eventually become too great to be resisted by the physiology of bone tissue alone and, thus, remodeling of bone becomes necessary. Changes in cross-sectional geometry allow changes in robusticity, which is the strength that results from remodeling against force-induced strains.

There are five types of strain that can be experienced by a bone: tension, compression, bending, shearing, and torsion. Three types of strain are particularly important in most loadings of human limb bones: compression, bending, and torsion (Table 3.1). Compression is a simple strain that causes shortening of the bone. Bending, on the other hand, is a complex strain because it causes two types of strain: tension on one side, and compression on the other. Torsion is strain that twists an object. Strengths against the different strains are calculated using cross-sectional geometries of the long bones, such as the femur (Alexander, 1968; Swartz, 1996). Compression is the most common strain experienced by bone, and bones best resist it by increasing cortical bone area (Swartz, 1996). Compressional strength, consequently, is calculated by measuring cortical bone cross-sectional area (CA).

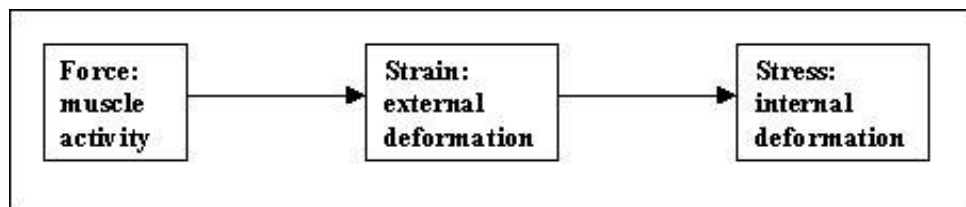


Figure 3.1. Chain of events that occur during mechanically induced bone remodeling. Created by Elizabeth Weiss from San Jose State University.

Table 3.1. Summary of cross-sectional properties and the type of strength they measure

Cross-sectional Property	Strength Measurement
Areal measurements	
Cortical Area (CA)	Compression Strength and Torsion
Total Area (TA)	Compression Strength
Inertial Measurements	
<i>Moments of Inertia</i>	
I_{ap}	Bending Strength in the anteroposterior plane
I_{ml}	Bending Strength in the mediolateral plane
<i>Polar Moment of Inertia</i>	
$J (I_{ap} + I_{ml})$	Torsion Strength

Although compression is the most common strain experienced by long bones, bending is the type of strain most likely to break a long bone (Alexander, 1968). This is in part because the Haversian system is ideal for resisting compressive stresses and, thus, bone is less in jeopardy of breaking from compression than it is of breaking from bending stress. As a result, it is important to determine a bone's strength against bending strains. In order to calculate bending strength, moment of inertia or second moment of area (I) is used, which is equivalent to mass in a rotating system (Swartz, 1996). Moment of inertia is used to determine the magnitude and direction of bending strength; a greater I means a greater resistance to bending in a bone in a given direction. The best morphology, from a mechanical perspective, to resist bending strains is a hollow shaft with a large radius. A hollow shaft is better than a solid shaft because it decreases weight and, thus, eliminates excessive energy needed to move a heavy bone (Alexander, 1968).

Moment of inertia is measured through the center of gravity of a cross-section, which has both area and placement of particular components of area incorporated within it (Swartz, 1996). In order for the direction of bending strength to be determined, I must be defined with respect to particular axes. The axes are usually mediolateral (ml) and anteroposterior (ap) with respect to anatomical positions. The location of bending strength is indicated by ml and ap, with these referring to the axes around which the moments of inertia are calculated (Runestad et al., 1993). An I_{ml} to I_{ap} ratio allows one to calculate where bone remodeling has deposited new bone to prevent breakage from bending stresses (Swartz, 1996). For example, if most of the strain comes from the anterior and posterior sides, then the bone should have more cortical mass on its front and back (Figure 3.2) and a higher I_{ml}/I_{ap} ratio. The biceps brachii and deltoid attach on the front and back of the humerus and cause a strongly anteroposteriorly oriented humerus when used extensively in flexing and extending the arm.

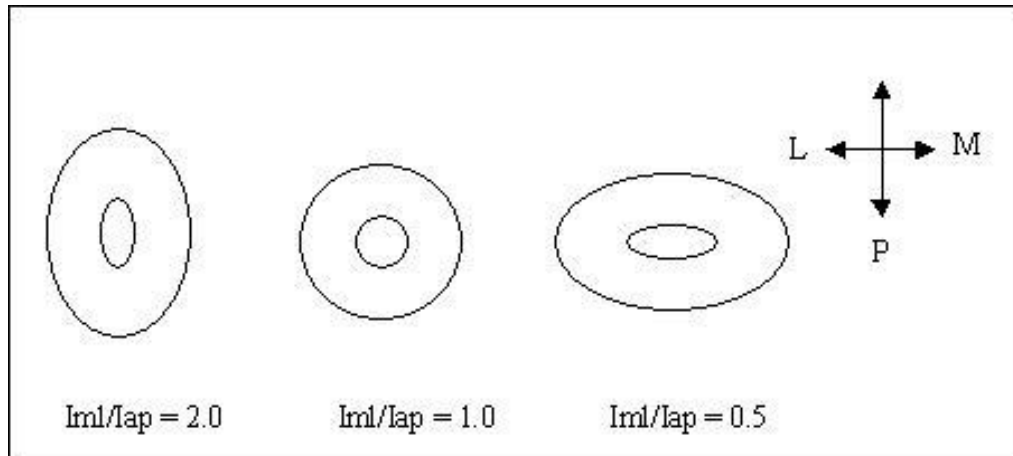


Figure 3.2. Cross-sectional shape as a result of strain direction. The left shows the result of anterior (A) and posterior (P) strains, the middle the result of few strains, and the right shows result of medial (M) and lateral (L) strains. Adopted from Ruff (1987).

Overall bending and torsion strengths are measured using the polar moment of inertia. Torsion often occurs close to the joints of limb bones because of the rotation of bones at joint sockets (Alexander, 1968). The polar moment of inertia (J) is the moments of inertia about the anteroposterior and the mediolateral axes combined; in other words, $J = I_{ap} + I_{ml}$ (Runestad et al., 1993). Hollow shafts give strength against twisting, which explains why the moment of inertia is used to calculate torsion strength. Unlike bending strength, torsional strength does not require strength in a specific direction, and, as such, the polar moment of inertia is used (Alexander, 1968).

The cross-sectional properties described above and outlined in Table 3.1 can be obtained through two main techniques: computer tomography scans (also known as CT-scans or CAT-scans) and radiographs (also known as x-rays). CT-scans are x-rays taken in 360 degrees and then assembled through computer software to provide the completed image. The cross-sectional image (which looks similar to a misshaped doughnut) is then fed through additional software (such as SLICE software) that calculates the cross-sectional properties. X-rays, on the other hand, need to be taken at two orientations (mediolateral and anteroposterior) and then the x-ray is used to measure inner and outer bone diameters. The measurements of inner and outer bone diameters are placed in formulae that utilize π to estimate cross-sectional shape and calculate the areal and inertial properties (Biknevicius and Ruff, 1992). X-rays tend to over-estimate cross-sectional strength, but as long as all the measures that are being compared were taken in the same manner, this need not be an issue (O'Neill and Ruff, 2004).

Cross-sectional Studies

Anthropologists have used limb bone cross-sections to examine the effects of division of labor, shifts in subsistence patterns, aging, and physical environments (Bridges et al., 2000; Feik et al., 1996; Ruff, 2000; Ruff and Hayes, 1983; Stock and Pfeiffer, 2001).

In an early study, Kimura and Takahashi (1982) studied femoral cross-sections from Japanese pre-agriculturalists (hunter-gatherer-fishers from 5500 to 2000 years BP – years before present) and Japanese industrial samples (autopsy specimens from anatomy classes). Kimura and Takahashi (1982) found the pre-agriculturalists had more anteroposteriorly -

oriented midshaft femoral cross-sections, which indicated high mobility since the muscles used for walking attach to the front and back (at the linea aspera) of the femur. The pre-agricultural male femora were also more anteroposteriorly oriented than were the pre-agricultural female femora. The authors also found that female femoral cross-sections changed little with shift from pre-agriculture to modern industrial cultures. It seems that females were less mobile than males in the pre-agricultural population (that is, the females walked less than the males did). Male femoral cross-sections, on the other hand, became more circular through time as seen in the industrial population. In industrial population, both sexes were sedentary (that is, they walked very little). Thus, cross-sectional geometry in the femora of both males and females are circular in the industrial population, which is consistent with a sedentary lifestyle.

Bridges (1989a) studied changes associated with the transition from a pre-agricultural to an agricultural subsistence in Tennessee Valley Amerindian populations, and found that male femoral cross-sections underwent few changes across this transition from hunting-and-gathering to agriculturalism, but that female cross-sections increased substantially in cortical bone. Bridges deduced that these changes occurred because females increased the use of their lower limb muscles through agricultural work, whereas males kept similar behavioral intensities from hunting and gathering practices. Bridges also found that female upper limb strength increased with the introduction of agriculture, which she attributed to the grinding of corn. Thus, Bridges concluded that females, but not males, increased their bone strength with the introduction of agriculture due to their intensified labor, which placed more stress on the bones.

Weiss (1998) used CT-scans on 34 adult males and 30 adult females from a Californian hunter-gatherer population to examine the cross-sections of femora and found that the male cross-sections were thicker and more anteroposteriorly oriented than those of the female, indicating that males had traveled more (Figure 3.3, see Weiss, 1998). Thus, a sexual division of labor likely existed in this pre-agricultural population, which included males traveling for hunting, trade, and warfare, and females staying home to prepare foods, gather, and watch the children. This negated the once popular notion that sexual division of labor first occurred with the onset of agriculture.

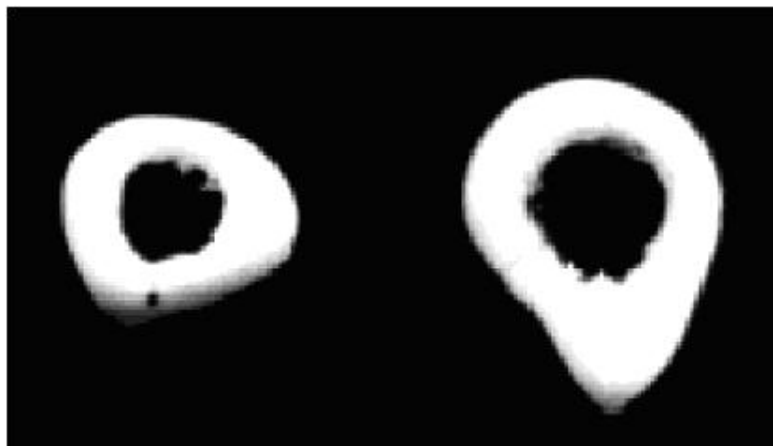


Figure 3.3. Left, a female circular femoral cross-section suggesting infrequent traveling; right, a male anteroposteriorly oriented femoral cross-section suggesting much traveling. Taken from Weiss (1998).

Pomeroy and Zakrzewski (2009) examined sex differences in a medieval Muslim population in Spain (N = 72) and compared them to an Anglo-Saxon United Kingdom sample (N = 42). The authors found more sex differences in the Spanish population than in the UK population; this difference may relate to religious traditions of Muslims that dictate a woman's realm is in the home whereas a man's realm is out in public. Mobility was further decreased among the Spanish women since they were not allowed out without a chaperone and had a bevy of domestic duties. The same limits were not placed upon the English women, which results in a reduction of sexual dimorphism (which is the difference between the sexes) among the Anglo-Saxon sample.

In Australia, researchers examined both upper and lower limb cross-sections to determine whether sex differences in hunter-gatherers would compare to ethnographic data on hunter-gatherer activity patterns. Carlson and colleagues (2007) found in a sample of 149 pre- and post-contact Australian Aborigine individuals that males and females did not differ in lower limb cross-sections, but upper limb cross-sections were more robust in males. Ethnographic data supports distance travel by both males and females; perhaps the greater upper limb robusticity in males is the result of hunting with the use of spears. Nonetheless, ethnographic reports suggest that females carried heavy items and ground food and as a result should also display robust upper limbs.

Sládek and co-researchers tried using femoral cross-sectional shape to determine whether Central Europe had settlements during the Late Eneolithic (2900–2000 BC). Sedentary behavior as indicated by femoral cross-sections would support the presence of settlements and corroborate archaeological research that indicated agricultural subsistence. The authors tested the hypothesis by looking for differences in femoral cross-sections between the Late Eneolithic sample and an Early Bronze Age (2000–1700 BC) sample who were known to be sedentary. Few differences were found between the two populations. However, males of the Late Eneolithic had longer anteroposteriorly oriented femoral shafts that indicated higher mobility than the Bronze Age males may have experienced. Contradicting this finding, females of the Late Eneolithic had rounder femoral shafts than Bronze Age females suggesting the Late Eneolithic females were less mobile than Bronze Age females, but the authors suggest this temporal difference within females may relate to body shape rather than activity patterns. Thus, Sládek and co-researchers concluded that since there is not strong evidence of greater mobility in Eneolithic populations and further research needs to be conducted.

Another example of bone remodeling research comes from Ledger and colleagues (2000) who found that 18th Century South African slaves had stronger upper limb cross-sections but weaker lower limb cross-sections compared to Later Stone Age African hunter-gatherers. Ledger et al. attributed these differences to the manual labor required of slaves as opposed to the high mobility experienced by hunter-gatherers. In a similar study, Stock and Pfeiffer (2001) compared Later Stone Age South African hunter-gatherers to 19th Century fishers from the Andaman Islands (between Sumatra and Borneo). Stock and Pfeiffer found that, while the hunter-gatherer population had more robust (stronger) lower limb cross-sections the fishing population had more robust upper limb cross-sections. Stock and Pfeiffer attributed these population differences to the use of particular muscles in relation to specific activity patterns, such as lower limb muscles being used for long-distance travel in the hunting group and upper limb muscles being used for rowing watercrafts, swimming, and fishing.

In the first study to examine direct environmental impacts on bone cross-sections, Ruff (2000) compared six Amerind populations (three non-agricultural and three agricultural populations; $N = 268$) occupying three different environments. Two of the populations (one non-agricultural and one agricultural) inhabited a flat region in the South Dakota Plains; two populations (one non-agricultural and one agricultural) lived in a coastal region of Georgia; and two populations (one non-agricultural and one agricultural) occupied mountainous regions in the Northern Great Basin and New Mexico. Ruff found that Amerinds who walked on mountainous terrain had more robust femora than those who walked on flat terrain. These terrain effects out-weighed the effects of subsistence patterns and were, therefore, more powerful forces in shaping femoral cross-sections than culture.

Although there is a vast body of literature (e.g., Jones et al., 1977; Trinkaus et al., 1994; Woo et al., 1981) that report positive relationships between bone loading and diaphyseal robusticity as mentioned above, and many anthropologists have used bone cross-sections to reconstruct past activity patterns (as described above), not all anthropologists agree that the use of muscles leads to alteration in bone that can, in turn, be used to understand activity patterns. Bertram and Swartz (1991), for example, reported that previous experiments using force-causing devices surgically inserted into the bone do not show evidence of bone remodeling, but result in a damage response similar to when bone has been broken or after other surgical interventions. They further suggest that evidence of atrophy (or bone loss due to lack of force) is more complex than a mere absence of bone remodeling due to decreased muscle use, for even those bones not normally affected by activity patterns suffer atrophy where there is an absence of force, such as in anti-gravity experiments or restraining movements in rats.

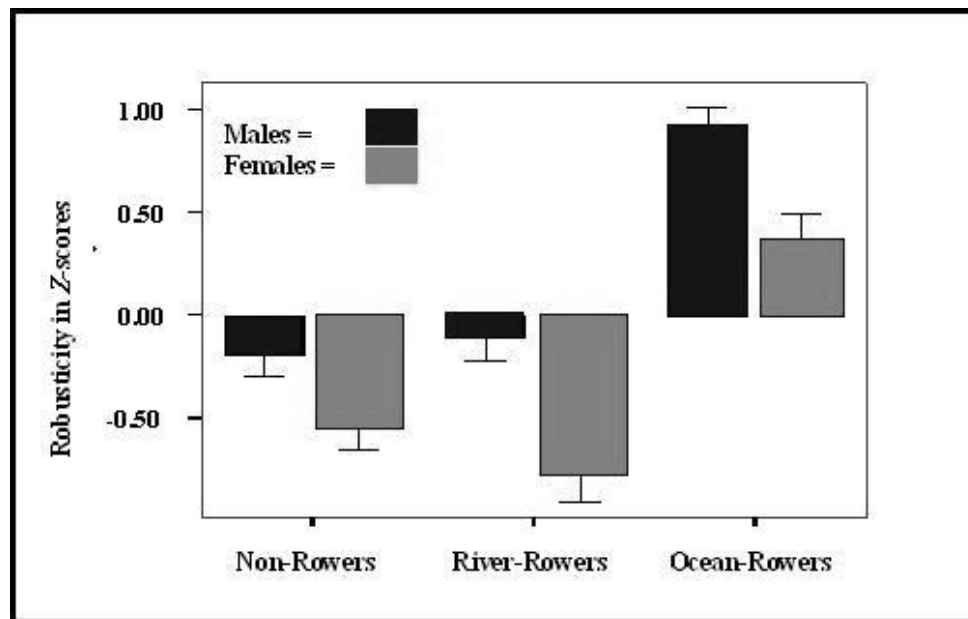


Figure 3.4. Cross-sectional robusticity examining sex and rowing differences that is standardized for humeral length (standardization for body mass results were similar). Taken from Weiss (2001a).

Stirland (1998) took another approach in trying to understand bone remodeling. She examined 100 adult males from the crew of the *Mary Rose*, which was a flagship of Henry VIII that sank in AD 1545, and 100 modern male divers. Stirland found in both samples that a greater amount of cortical bone did not correlate with greater muscle marker scores, which are often used as indicators of muscle use. In light of these findings, Stirland concluded that muscle markers were simply too subjective to be used reliably for the reconstruction of activity patterns. Stirland, however, did not consider the possibility that this discordance might be the consequence of problems with measurements of cross-sectional morphology for reconstructing activities. Interestingly, in an earlier study with the same skeletal remains from the *Mary Rose* compared to a Norwich sample from AD 1254 to 1468, Stirland (1993) found that the crew of the *Mary Rose* were less asymmetrical than the Norwich population and related this to activities the crew engaged in that required the use of both arms. Asymmetry studies of cross-sections have gained considerable popularity and will be discussed in the following section.

In another study, Weiss (2003a) looked at the potential effects of rowing on humeral strength in a skeletal sample of 358 individuals from seven populations. Weiss predicted that ocean-rowers would have stronger humeral cross-sections than river-rowers or non-rowers. Since rowing on oceans is mainly a male activity pattern (Suttles, 1990), analyzing the sex differences in humeral robusticity provided a control. Although ocean-rowing males had more robust humeri than did non-ocean-rowing males, the same differences showed up in females (Figure 3.4). Thus, Weiss concluded that such population differences were perhaps more correctly attributable to overall activity levels or some pre-existing biological factors (such as cold-adapted body shapes that tend to inflate cross-sectional strength measures) rather than to rowing. Churchill (1994) examined upper limb robusticity cross-sections and body shape of modern and archaic humans. He concluded that the high upper limb robusticity in some modern populations, such as the Aleut, likely reflect the strenuous activities engaged in that caused bone remodeling and adaptation to geographical locations overlain atop of a basic *Homo sapiens* upper body plan rather than emphasize body shape differences. Weiss also found very clear sex differences, with greater male robusticity in all studied populations. Sex differences in robusticity have often been interpreted as due to sexual division of labor (e.g., Bridges, 1989a; Ruff, 1987). However, many physical sex differences are known to be in large part due to biology, such as genetic or hormonal effects. Hence, both population and sex differences in cross-sectional morphology need to be considered when testing hypotheses about the effects of cultural activities.

Weiss's 2005 study of Quebec prisoners of war and New Mexico suburbanites also calls into question the usefulness of cross-sections in reconstructing past activities. The study used measures of cross-sectional robusticity and asymmetry (based on humeral areal and inertial cross-sectional components) to test the prediction from bone remodeling theory that a physically active 18th Century Quebec prisoner of war sample (N = 25) should have more robust and asymmetrical humeri than a non-physically active 20th Century New Mexico suburbanite sample (N = 27). Narrative accounts document that the prisoners of war engaged in labor-intensive activities and these activities were confirmed by observations of osteoarthritis and other pathologies. The suburbanite sample, for the most part, did not engage in such activities. The prisoners had higher levels of osteoarthritis, which is another indicator of activity levels, than the suburbanites (e.g., 80% vs. 22%). For cross-sectional robusticity, the populations did not differ significantly in total area, cortical area, moment areas of inertia

about the mediolateral plane, or polar moment area of inertia (Figure 3.5). The Quebec prison sample did have significantly higher values for moment areas of inertia about the anteroposterior plane. For asymmetry, the populations did not differ in any of the values (total area, cortical area, moment areas of inertia about the mediolateral plane, moment areas of inertia about the anteroposterior plane, or polar moment of inertia). Thus, examinations of cross-sectional robusticity and asymmetry failed to conclusively confirm the hypothesis that intensive labor leads to changes in humeral morphology, but the significant findings were in the right direction. Possible explanations for the lack of differences include poor diet (impeding bone remodeling) and excessive use of both left and right arms. The one significant finding suggests that cross-sectional shape may be more useful in reconstructing activity patterns than amount of bone in a cross-section. This seems to support that bending and torsional stresses are more likely to break bone whereas bone is more adapted to resisting compression stresses and thus does not need to remodel as much to resist these stresses. Asymmetry studies have been hailed as being able to eliminate some of the inherent problems in cross-sectional studies, such as body shape differences, and therefore may be more useful in reconstructing activity patterns. Asymmetry studies will be reviewed in greater detail in the following section.

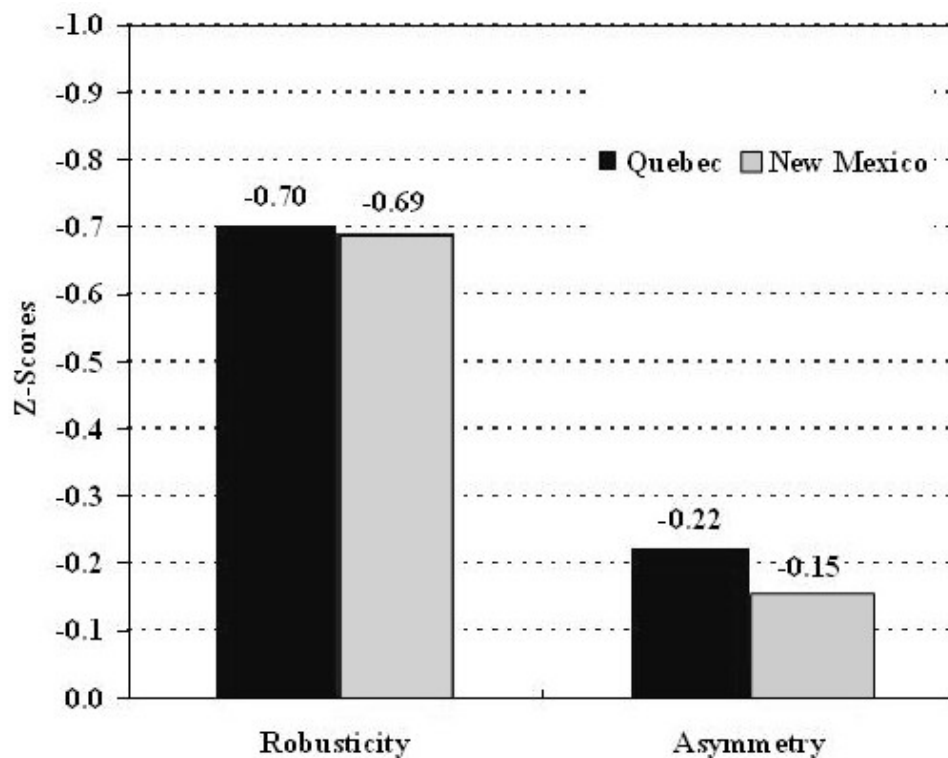


Figure 3.5. Cross-sectional robusticity (an aggregate of cross-sectional properties) and asymmetry between Quebec Prisoners of War who were labor intensive and non-labor intensive New Mexico suburbanites. The differences are not significant. Taken from Weiss (2005).

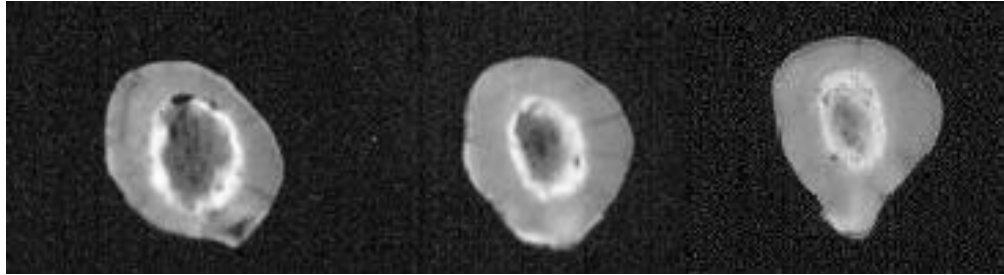


Figure 3.6. Kennewick Man's CT-Scans at 80%, 65%, and 50% (From Left to Right) of Bone Length. Taken by Dr. J.C. Rose of the University of Arkansas, Fayetteville.

In an interesting addition to the usefulness of cross-sections to reconstruct activity patterns, Kennewick Man's lower limbs were CT-scanned (Figure 3.6). Kennewick Man is one of the very few early Holocene (circa 9000 years BP) skeletons found in North America. His antiquity, alleged Caucasoid facial features, and the arrowhead lodged in his hip made this find remarkable. Using femoral cross-sections obtained via computer tomography, Weiss (2001b) examined the skeletal remains of Kennewick Man and compared them to Pleistocene (Ice Age) and Holocene (post-Ice Age) hunter-gatherers, as well as agricultural Amerinds. Comparisons revealed Kennewick Man's CA/TA ratios are similar to other preagricultural groups and are in-between Pleistocene and Holocene groups. Concerning the *Iap/Iml* ratios, Kennewick Man's cross-sections are the most anteroposteriorly oriented, indicating high mobility (Figure 3.7). Kennewick Man appears to have behaved like other Holocene hunter-gatherers – hunting small animals and gathering wild vegetables. Kennewick Man may have engaged in some big game hunting behavior like his Pleistocene ancestors and he still retained some Pleistocene adaptations. When examining Kennewick Man further, his robusticity is remarkable considering his age (around 45 years old) and his body mass as calculated by femoral head would have made him more similar to Pleistocene populations. It may be that he was overall more robust than later Holocene populations and that this robusticity was due to Pleistocene genetic adaptations (that disappear in later Holocene populations). Yet, any conclusions have to be viewed cautiously because of his injury, and the asymmetry of his sciatic notches that indicate pathology. Moreover, he is just one individual.

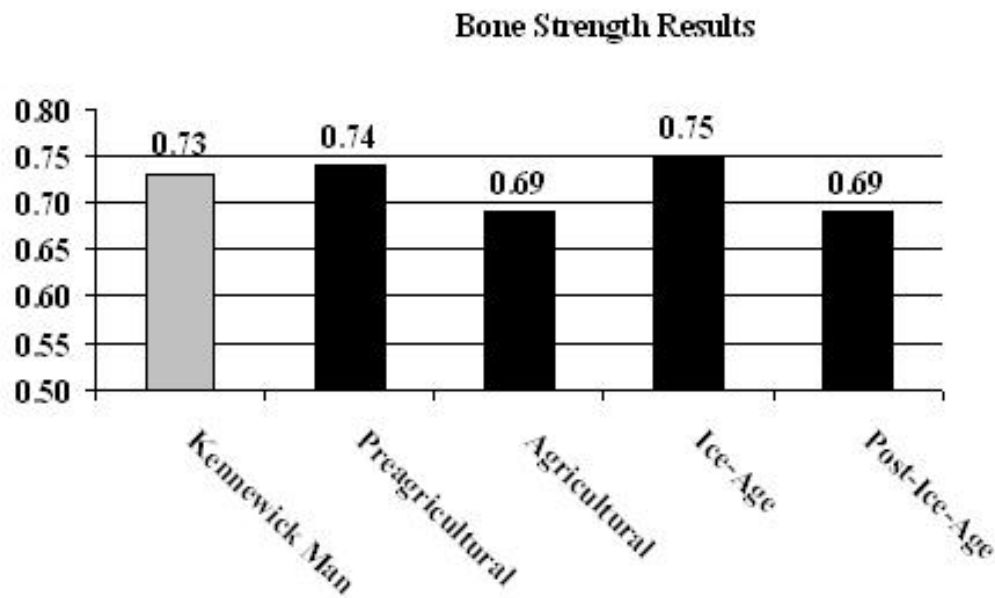


Figure 3.7. Bone Strength Results as measured by the ratio of Cortical Area over Total Area and averaged for the three cross-sectional locations (80%, 50%, and 35% of femoral bone length); Pre-agricultural group includes both Pleistocene and Holocene populations, whereas Agriculturalists include only Holocene populations. Taken from Weiss (2001b).

Cross-sectional Asymmetry Studies

Anthropologists also use asymmetry, the percent difference between right and left bones, to determine activity patterns. This type of asymmetry is often referred to as bilateral asymmetry, which differs from fluctuating asymmetry, and it is nonpathological in human upper limbs and relates to handedness. Fluctuating asymmetry is defined as the random difference between measures of a bilateral trait that results from disturbances in the environment during growth, which is indicative of pathology, nutritional stress, or other factors affecting health (Fields et al., 1995). Bilateral asymmetry can be either measured as directional (which usually assumes that most people are right-handed and therefore the right arm will be stronger) or non-directional (which just takes into account the difference between the two sides and does not assumed right-handedness). Evidence of activity-induced bilateral asymmetry in humeral bones comes primarily from research on athletes (e.g., Haapasalo et al., 2000; Kontulainen et al., 2003). For example, Haapasalo and coworkers (2000), using computer tomography, examined upper limb bilateral humeral asymmetry in male tennis players ($N = 12$) who had all begun their playing careers early in life, and control subjects ($N = 12$) who were matched for age and weight. Tennis players had greater asymmetry levels in midshaft and distal humeral measurements than did the control group. Variation within each group was large, which implies that additional factors affect asymmetry. Another study, by Kannus et al. (1995), utilized females by examining bone mineral density using DXA scanners on tennis and squash players ($N = 105$) and a non-playing female control group ($N = 50$) to determine the effects of activity and age on bone. Levels of upper limb asymmetry were higher in the female athletes compared to the non-playing females. Athletes who started

playing before menarche (which is the onset of menstruation) had two times greater bone remodeling in the playing arm than individuals who started playing after menarche. However, athletes who started playing after the onset of their menstrual cycles still exhibited greater asymmetry values than non-players. Kontulainen and coworkers (2003) examined female racquetball players (N = 36 for young starters; N = 28 for old starters) and a non-playing control group (N = 27) to determine the effect of sports on upper limb cross-sectional shape. Racquetball players had greater asymmetry values compared to the control group and those who started playing at young ages had the greatest degrees of asymmetry. Nevertheless, individuals who started playing racquetball as adults had greater asymmetry levels than those who did not play racquetball.

Research on athletes supports the assumption that activity differences can cause measurable differences in upper limb bone bilateral asymmetry. Based on this, anthropologists utilize humeral cross-sectional asymmetry to examine effects of such behavioral distinctions as sexual division of labor and differences in subsistence patterns (e.g., Maggiano et al., 2008; Sparacello and Marchi, 2008; Stock and Pfeiffer, 2004; Wescott and Cunningham, 2006). Maggiano and colleagues (2008) linked sex differences in humeral asymmetry of Mayan populations (250–700 AD) – in a location that developed from a salt producing city to a commercial port – to a division of labor. Females (N = 35) had consistently low levels of asymmetry (associated with childcare and food preparation). Males (N = 47) experienced a significant decrease in asymmetry through time, which may have been related to an increase in administrative work.

A study with earlier populations found sex differences as well. Sparacello and Marchi (2008) examined 33 humeral pairs from a Neolithic population (6000–5500 BP) and a medieval population (10th–15th Century) in Italy and found asymmetry decreased in males, which they tied to stone axe use by Neolithic males. Female asymmetry was low throughout time, which they connected to mortar and pestle use for grinding grains. Another study of remains looked at humeral comparisons between Late Upper Paleolithic and Neolithic Europeans (N = 22) and also found that asymmetry decreased over time (Marchi et al., 2006). In this case, as well, low asymmetry in females was associated with grinding grains while decrease in males was linked to a concurrent decrease in hunting.

In England, Mays (1999) examined humeri of 111 individuals from the 11th to 16th Centuries to look at sex differences. Males were more asymmetric than females, which Mays coupled with craftsmanship (such as woodworking). Symmetry in females was probably due to their versatility; they created textiles, prepared foods, and engaged in craftsmanship. Monks were less active than laypersons and had accordingly symmetrical humeri.

Bridges and coworkers looked at humeri of Native Americans (N = 372) who had subsisted in a hunter-gatherer period (50 BC–200 AD), a transitional period when native seeds were ground (600–1050 AD), and a maize agricultural period (1050–1250 AD). Throughout time, male asymmetry decreased slightly, but female asymmetry increased in the maize agricultural period, which may be due to easier processing of maize compared to that of native seeds. Wescott and Cunningham (2006) examined humeri of 16th to 19th Century horticultural Great Plains Amerinds (N = 222) and found a decrease in sex differences as a result of an increase in male asymmetry. Females showed greater asymmetry than males, which could be due to food processing methods without the use of mortars and pestles.

In Weiss's study (2009a), two Amerindian prehistoric hunter-gatherer populations (British Columbia and California sites) with a sample size of 136 were examined to determine

whether levels of sexual dimorphism in humeral bilateral cross-sectional asymmetry related to differences in activities along sex lines in these populations. The California site (CA-Ala-329) is located on the southeastern side of the San Francisco Bay and the temporal span of the site is 2180–250 BP. The British Columbian Amerinds are from Prince Rupert Harbour and come from the Middle Period that dates from 3500 years BP to 1300 years BP (Cybulski, 1992). The site is located on British Columbia's northwest coast 50 kilometers south of the Alaska Panhandle. Low levels of bilateral asymmetry were found in California female Amerinds who ground acorns with the use of both hands. Low levels of asymmetry also were found in British Columbian males, who utilized both arms in rowing canoes, compared to California males. Higher asymmetry values were found in California male Amerinds whose activities were dominated by hunting and warfare with spears. Thus, even when cross-sections are founded by biology, asymmetry studies seem to be a useful to reconstruction activities, especially when coupled with archaeological evidence. Less complicated measures of activity include muscle markers and osteoarthritis scores, both of which are collected from macroscopic external bone examination.

3.4. Use of Muscle Marker Data

Muscle Markers (i.e., musculoskeletal stress markers) are distinct skeletal markings that occur where a muscle, tendon, or ligament inserts into the blood-supplying periosteum and the underlying bony cortex (Figure 3.8). Bone remodeling theory, as mentioned above, states when muscle insertion sites are subjected to stress, blood flow is increased, which stimulates bone forming cells that result in bone hypertrophy and increased size of musculoskeletal stress markers (Chamay and Tschantz, 1972; Ruff et al., 2006; Weiss, 2003, 2004; Woo et al., 1981). Bones experience forces from muscle use throughout an individual's life to which the bone must respond to prevent breakage. Theoretically, muscle use is important in remodeling bones and maintaining strength because muscle usage places the stress on bones necessary to activate osteoblasts (Hamill and Knutzen, 1995). Where muscles attach, activity increases bone robusticity. Consequently, anthropologists typically view more pronounced muscle markers as being the direct result of muscle use. Thus, bone remodeling theory has led anthropologists to conclude that large, well-defined muscle markers are the result of continued muscle use in daily and repetitive tasks (especially when started at a young age and continued through adulthood), which has made muscle markers ideal for reconstructing past lifestyles.

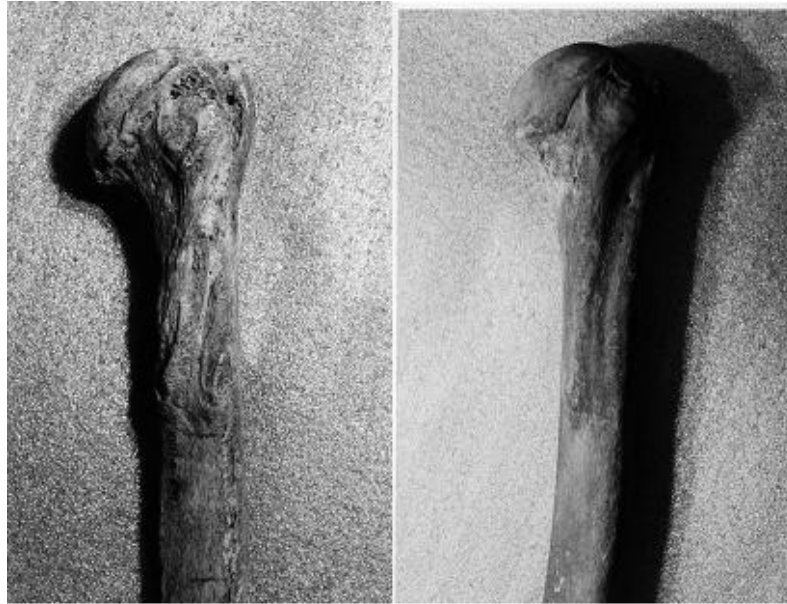


Figure 3.8. Image of a humerus with well-defined muscle markers (left) and less-defined muscle markers (right). These photos were taken by Jerry Cybulski, courtesy of the Canadian Museum of Civilization.

The Hawkey and Merbs (1995) method is most commonly used for taking muscle marker scores. Their method is ideal because they have outlined a set of criteria that have low intra-observer and inter-observer error rates (which means that the same scorer will give a consistent score over several attempts for the same bone and that two or more scorers would give the same score on the same bone) and the guidelines for scoring muscle markers are straightforward. Muscle markers are scored on two dimensions: robusticity and stress lesion. Within these two categories, there are four specific grades, with the absence of the expression being grade 0. However, the categories are actually on a continuum, and after the scores are taken separately, they are converted from 0 to 3 in each category to 0 to 6 in one category, with 0 being the lowest robusticity and 6 being the greatest stress lesion. In robusticity grade 1 (R1), the outer portion of the bone is only slightly rounded with elevation apparent when touched, no distinct crests or ridges are present; R2, the outer portion of the bone is uneven, with a mound-shaped elevation clearly visible; and in R3, distinct sharp crests or ridges are present and there may be a small depression between crests, although this depression does not extend into the cortex or the outer portion of bone. The stress lesion category is defined as pitting into the cortex with grade 1 containing shallow pitting into the cortex that is less than 1 mm in depth. Stress lesion grade 2 has pitting between 1 mm and 3 mm in depth and stress lesion grade 3 is when pitting is greater than 3 mm in depth with an area covering more than 5 mm in length.

Anthropologists have addressed issues regarding sexual division of labor, group differences in specific activities related to culture, effects of agriculture on past populations, and many more using muscle markers (e.g., al-Oumaoui et al., 2004; Chapman, 1997; Eshed et al., 2004; Hawkey, 1998; Hawkey and Merbs, 1995; Lai and Lovell, 1992; Molnar, 2006; Papathanasiou, 2005; Peterson, 1998).

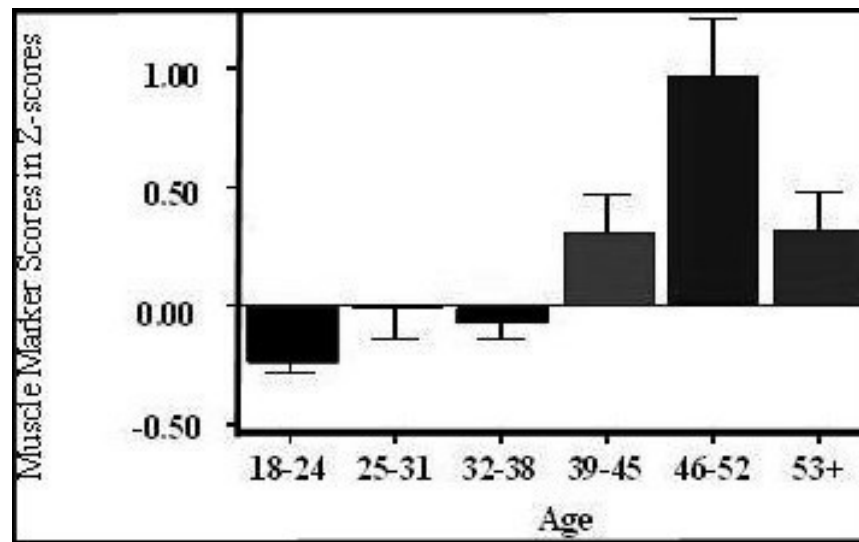


Figure 3.9. Muscle marker and age correlation from British Columbian Amerind sample dating between 3,500– 1,500 yrs BP. Taken from Weiss (2003b).

However, complications in using muscle markers to reconstruct activity patterns have also been discovered. Some of these complications have resulted in muscle marker patterns that have emerged regardless of the population examined. Researchers, for instance, consistently find that older individuals have more pronounced muscle markers than do younger individuals, which many anthropologists relate to the stress of activity patterns that accumulate over time (e.g., Molnar, 2006; Robb, 1998; Weiss, 2003b; Wilczak, 1998). See Figure 3.9 for an example in British Columbian hunter-gatherer Amerinds. Anthropologists using muscle markers to reconstruct past lifestyles frequently consider age differences to enable accurate reconstructions (e.g., Hawkey and Merbs, 1995).

Additionally, in many skeletal samples, males have higher muscle marker scores than females (e.g., Cohen, 1989; Molnar, 2006; Steen and Lane, 1998). A few studies have found certain muscle markers to be higher in females than in males (al-Oumaoui et al., 2004; Chapman, 1997). These reverse sex differences are more likely to be due to activity pattern differences rather than biological sex differences since they are the exception rather than the norm. Yet, these differences may disappear if one employs aggregate variables in the studies. Anthropologists most often attribute sex differences to differences in activity patterns (e.g., Chapman, 1997; Molnar, 2006; Peterson, 1998; Wilczak, 1998). Weiss (2003b, 2004, 2007), however, examined sex differences in muscle markers in several populations and found that males had higher muscle marker scores than females, but that this sex difference disappeared when controlling for size. It is, therefore, possible that sex differences in muscle markers are often due to differences in body size rather than activity patterns. If the sex differences do not disappear when controlling for body size, then attribution of sex differences to activity patterns strengthens. Finally, it is important to note that it is complicated to determine whether sex differences are a result of size differences, which can lead to differences in activity patterns, or whether the reverse is true.

Table 3.2. Muscles that attach on the humerus that are frequently used to reconstruct activity patterns. Note that actions of muscles overlap, which validates the use of aggregation

Muscle	Attachments	Action
Pectoralis major	Clavicle; sternum; ribs 1-6 TO greater tubercle of humerus and intertubercular groove	Arm internal rotation; arm horizontal flexion; arm flexion; arm extension
Latissimus dorsi	Spinous process of thoracic vertebrae 6-12 and lumbar 1-5; lower 3-4 ribs; iliac crest; inferior angle of scapula TO intertubercular groove on humerus	Arm internal rotation; arm adduction; arm extension
Deltoid	Lateral third of clavicle; acromion process; spine of scapula TO deltoid tubercle on humerus	Arm abduction; arm flexion; arm horizontal flexion; arm horizontal extension; arm internal rotation
Teres major	Posterior surface of scapula at the inferior angle TO lesser tubercle of humerus	Arm internal rotation; arm extension; arm adduction

Anthropologists also have concerns over the lack of objectivity when collecting data on muscle markers and using these data to reconstruct activity patterns (Jurmain, 1990, 1999; Stirland, 1998; Zumwalt, 2005). Work by Hawkey and Merbs (1995) and Robb (1998) have standardized less subjective ways of collecting muscle marker data, some of which the author uses in the present study. In addition, Weiss (2003b) advised the use of aggregated muscle marker variables to improve muscle marker studies by enhancing construct validity and reducing error variance in the data; Table 3.2 highlights the muscles insertion sites for the humeri and their actions, which demonstrates how muscles work together on the same actions. For more in-depth discussions of muscle marker issues, see Jurmain (1999), Robb (1998), Stirland (1998), and Weiss (2003b). Zumwalt (2005) has suggested using three-dimensional laser computer technologies, as have been used in anthropological dental studies, to quantify muscle markers more objectively, but this is an expensive and time-consuming alternative. One of the benefits of muscle marker studies has always been the relative low cost and ease of data collection.

Since the above-mentioned studies (especially, Weiss, 2003b, 2004) drew attention to complications of using muscle markers to reconstruct activity patterns, few changes have occurred to how muscle markers are studied. Ranking muscle markers is a method anthropologists are beginning to use to settle questions about sex differences. Eshed and colleagues (2004), for example, employed ranking methods in their study of muscle markers in Levant Natufian hunter-gatherers compared to muscle markers of Neolithic farmers in the Levant. Using rankings, the authors noticed the farmers had greater upper limb muscle marker scores than did the hunter-gatherers. Furthermore, males and females had differences in muscle markers in both groups, which the authors attributed to sex differences in labor. Size differences, however, may explain some of these differences between males and females or even between the groups. Ranking helps to resolve some size issues, but only if the ranks do not correlate with body size.

Another recent study looked at muscle markers of 342 individuals from five populations to determine activity patterns in the Iberian Peninsula (al-Oumaoui et al., 2004). The authors found that, after controlling for age, females had lower muscle marker scores than males (with a few notable exceptions). They coupled the lower female scores to less walking and more domestic labor in females compared to males who engaged in agricultural activities. In addition, it appears that sexual dimorphism increased in Iberia throughout time, which the authors linked to a change in activity patterns. They failed to control for size differences, which may explain the difference in muscle markers in some populations where males are significantly larger than females. Perhaps the earliest population was the least sexually dimorphic in body size, as well as in muscle markers.

Molnar (2006) examined muscle markers of 39 Stone-Age individuals on a Baltic Sea island. She scored muscle markers in various age groups to determine if archery, harpooning, and kayaking had a significant effect on upper limb morphology in the population. She found that, when examining muscle markers related to these activities, males had higher muscle marker scores than did females. Without body size controls, it is not possible to determine whether these differences between males and females are related to activity or simply due to larger male body sizes compared to females.

Weiss (2003b, 2004) has demonstrated that muscle markers correlate with body size, and yet muscle marker studies continued without controlling for body size (al-Oumaoui et al., 2004; Eshed et al., 2004; Molnar, 2006). Weiss (2007), however, used both aggregated muscle markers and separate muscle markers with size and age controls to attempt an activity pattern reconstruction using the remaining significant sex differences in a California Amerind population with a sample size of 102. The site located southeast of San Francisco dates from 2180 to 250 years BP (which is pre-European contact). These California Amerinds were hunter-gatherers in a location of rich environmental resources and large population sizes. Her results showed that older individuals had higher muscle marker scores than did younger individuals, which is not surprising and corroborates many other studies (e.g., Chapman, 1997; Kennedy, 1983, 1989; Molnar, 2006; Robb, 1998; Weiss, 2003b, 2004; Wilczak, 1998). Results from this sample also showed that, in using the aggregate measure of humeral size as a predictor variable, individuals with larger humeri had higher muscle marker scores than did individuals with smaller humeri, thus extending earlier work by Weiss (2003b, 2004). Without controlling for body size, one may draw faulty conclusions on activity patterns, especially when comparing sexes or different populations, or populations over time. Males had higher upper limb muscle marker scores than did females, which is related in part to body size. Using a partial correlation controlling for humeral size and age, some of the muscle markers of males and females still differed; the sex difference in muscle markers seemed to be partly the result of sex differences in body size and perhaps partly because of activity patterns. Consequently, when muscle markers were ranked in males and females and compared to the effect of size on muscle markers, results show that the highest ranking in males was also the muscle marker that had the highest correlation with humeral size. A suite of muscle markers remained higher in males than in females. With the exception of one of the muscles (i.e., *teres major*), these muscles are usually associated with throwing or pitching motions, as in baseball (Hamill and Knutzen, 1995). Throwing is usually an activity related to handedness, which may explain the apparent right-handed trend. The *teres major* is associated with internal rotation only when there is resistance in the action involved, such as pulling ones arm through water (Hamill and Knutzen, 1995). Therefore, it is possible that the general

trend in right humeral muscle markers is associated with the male California Amerinds throwing spears with a resistant phase of pushing or pulling the spear through something either during hunting or interpersonal aggression. Obsidian points embedded in the skeletons indicate males were victims of interpersonal aggression (Jurmain, 1988; Jurmain and Bellefemine, 1997). Additionally, many male burials included obsidian points, whereas female burials lacked these artifacts (Leventhal, 1993). Bones of various animals and shafts for points were abundant at CA-Ala-329, which support the hunting or throwing argument. Of course, other activities could cause the sex difference in muscle markers.

In summary, muscle markers are likely good indicators of activities, but controlling for age and body size are important to avoid mis-constructing activities and de-emphasizing the importance of female labor. Osteoarthritis, on the other hand, has other complications.

3.5. Osteoarthritis Scores: Use of Joints and Activities

Osteoarthritis (also known as degenerative joint disease and osteoarthrosis) is the “gradual breakdown of the cartilage between the adjoining bones of a joint so that the articular surfaces come into direct contact” (Ubelaker, 1989:108). The physical attributes that are used to score osteoarthritis in skeletal remains are lipping (a build-up of osteophytes among the margins of the bone joints and vertebrae), eburnation (a polished area on the bone), and porosity (when bone joints appear very porous) (Figure 3.10). Osteoarthritis is the most ubiquitous trait in skeletal collections, and although many call it pathology, this erosion of cartilage is a normal process of aging and has been said to be the consequence of long-term mechanical stress to the area (Ubelaker, 1989).

The prevalence of osteoarthritis has necessitated its extensive study by physical anthropologists. Nevertheless, much is still unknown about osteoarthritis. Many causes of osteoarthritis have been discussed, such as genetic factors (Merbs, 2001; Spector et al., 1996), mechanical loading (Šlaus, 2000), and body weight (Heliovaara et al., 1993; Weiss, 2005b, 2006a). The most important cause of osteoarthritis for anthropologists working on reconstructing activity patterns is that of repetitive mechanical loading (Cope et al., 2004; Jurmain, 1999; Lovell and Dublenko, 1999; Šlaus, 2000; Waldron, 1997).

Defining the main cause of osteoarthritis as resulting from repetitive mechanical loading has led to the conclusions that severe osteoarthritis scores on specific joints, especially when one has controlled for age, are the result of continued use of specific muscles and joints in daily and repetitive tasks, which has made them useful for reconstructing past lifestyles. Questions regarding whether males and females differed in activity patterns, whether groups differed in specific activities related to food production and trade, what effects shifts in subsistence patterns had on past populations, and many more have been tentatively answered using osteoarthritis scores (e.g., Derevenski, 2000; Lovell and Dublenko, 1999; Šlaus, 2000). It is important to note, however, that many anthropologists are cautionary when trying to reconstruct specific activities; that is, they acknowledge the complexity of osteoarthritis formation and mechanical loading causes (e.g., Bridges, 1992; Jurmain, 1990, 1999; Weiss and Jurmain, 2007).

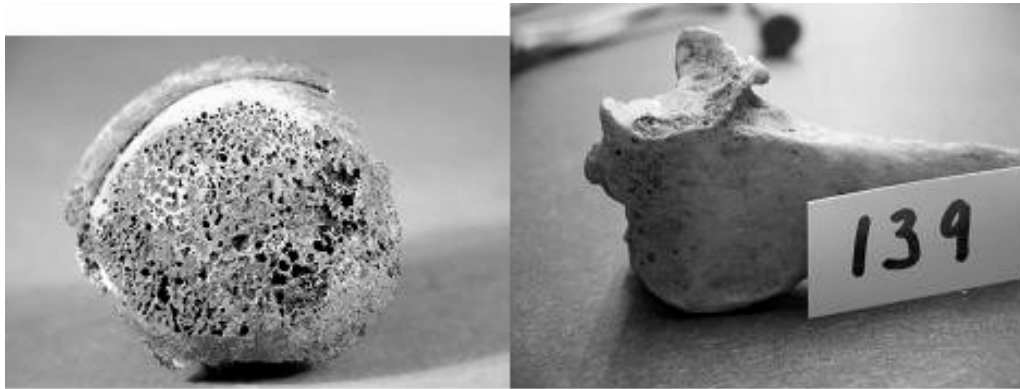


Figure 3.10. Osteoarthritis on a humeral head showing porosity (left) and osteoarthritis on the radius showing lipping (right). Photos taken by Elizabeth Weiss of San Jose State University.

Recent activity-related studies have been published on a variety of populations; Rojas-Sepúlveda and co-workers (2008), for instance, examined vertebral osteoarthritis (as classified by lipping and eburnation or polishing) in 83 individuals from Colombian sites that date between the 11th and 13th Centuries, which is prior to European contact, to reconstruct activity patterns. The authors excluded porosity as an indicator of osteoarthritis due to its controversial role in the diagnoses of osteoarthritis (see Jurmain, 1999). In their study, results indicated 83% of the sample were inflicted with vertebral degenerate joint disease (osteoarthritis), which was attributed to occupational stress related to carrying heavy loads, such as those in salt production that were documented in later periods by Europeans, on the back. These loads may have weighed 24 kg and have been carried longer than 50 km over difficult terrains.

In 2007, a study on Siberian hunter-gatherers by Lieverse and colleagues also tied osteoarthritis to cultural activities. Lieverse and co-workers examined two periods of Siberian prehistory – pre-hiatus Kitoi (6800–4900 BC) and post-hiatus Serevo-Glaskovo (4200–1000 BC) – to determine whether the 700-year gap that seemed to have disrupted the Cis-Baikal region of Siberia cultural continuity had an effect on mobility adaptations in populations before and after the hiatus. The assumption has been made that the later population utilized a greater variety of resources while the Kitoi population was more focused on marine sources that were local. After the hiatus, it appears that the population may have been different both biologically and culturally. If culture had changed, then activities that led to osteoarthritis should be different in pre-hiatus versus post-hiatus populations. By examining osteoarthritis patterns in the upper and lower limbs, the authors found that frequency of osteoarthritis did not differ between the two periods. Distribution of the osteoarthritis, however, showed slight differences between the two populations and between sexes. For example, they found a lower level of vertebral osteoarthritis among pre-hiatus females compared to their contemporary males and compared to post-hiatus females, which is suggestive of less load bearing in the pre-hiatus Kitoi females (perhaps due to more local use of resources). Additionally, males of the pre-hiatus group had greater knee arthritis than females of the same group, which suggests that males were more mobile than females; interestingly, post-hiatus males seemed to be less mobile, too, with a decrease in knee osteoarthritis compared to pre-hiatus males. There are overall fewer differences between sexes in the later population, which may indicate less

sexual division of labor. Thus, the two populations are largely similar, suggesting that the different adaptations to the environment were minimal. But, the variances that were apparent seemed to affect males and females in opposite direction, with increased osteoarthritis in females in the post-hiatus period that suggests carrying loads further and thus greater mobility, and a decrease in osteoarthritis in males after the hiatus that suggests local use of resources and low mobility.

In another recent study, Cope and co-researchers examined osteoarthritis in the hand. Skeletal remains from the United Arab Emirates dating from the Umm an-Nar period (2500–2000 BC) through the Iron Age (1200–400 BC) were examined. Cope and co-workers looked at 650 trapezium, first, and second metacarpal bones (these are wrist and palm bones) from around 155 adult individuals to determine osteoarthritis rates and their relation to sex and robusticity. They found that osteoarthritis was positively related to robusticity and was found more frequently in males than in females (as an aside, their sample contained a larger male sample than female sample). These results, Cope et al. suggest, relate to increased robusticity as an indicator of increased activity and that increased activity also led to greater osteoarthritis rates. Some of the activities that were suggested to have contributed to the osteoarthritis include making fishing nets of palm fronds, creating pottery, building mud huts, harvesting, and opening mollusks. They also concede the importance of age and contend that the relatively young age of their sample suggests extensive stresses to the hand that resulted in early onset osteoarthritis.

The best-established findings in the anthropological osteoarthritis literature relate to age differences. Older individuals have more severe osteoarthritis than do younger individuals, which many anthropologists relate to the stress of activity patterns that accumulate over time (e.g., Kahl and Smith, 2000; Larsen, 1995; Merbs, 2001; Waldron, 1997). Figure 3.11 illustrates the age correlation in a sample of 91 individuals from British Columbia and Quebec prisoners of war. Although these populations are very different, combining their results does not disrupt the age correlation with osteoarthritis. Researchers using osteoarthritis scores to reconstruct past lifestyles frequently take age differences into account to enable more accurate reconstructions (e.g., Kahl and Smith, 2000; Šlaus, 2000). Age differences, however, vary greatly and the degree of osteoarthritis in older individuals is intertwined with genetics, body mass, and mechanics (Weiss and Jurmain, 2007).

Although age is an important consideration in osteoarthritis frequency, certain joints that are used excessively due to activities may be prone to osteoarthritic changes earlier in life. The late Dr. Patricia Bridges (1992) found significant osteoarthritis in female neck bones of Alabama prehistoric Indians. She associated this early onset of osteoarthritis with the fact that women may have been carrying objects on their heads. Her conclusion is supported by later artifacts of carrying bags made to fit on the head and suggest a continuum of culture in this part of the Americas. Other areas of the Americas have seen a continuation of cultural practices that can be reconstructed using osteoarthritis frequency, such as the use of an atlatl (a type of spear thrown for hunting) by Aleuts and Eskimo prehistoric Alaskan populations documented in Dr. Merb's research; Merbs (1983) has found high levels of osteoarthritis in male upper limbs that are associated with these hunting techniques. Clavicular osteoarthritis also is frequent and severe in these populations as a result of kayaking.

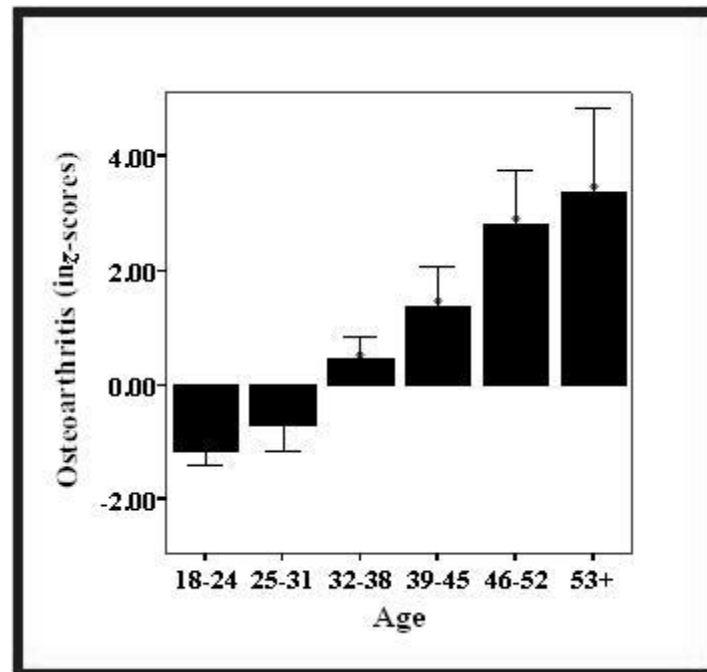


Figure 3.11. Osteoarthritis increases with age as seen here in a sample of 91 Quebec prisoners of war and British Columbian Amerinds pooled. Modified from Weiss (2005b).

Sex differences in osteoarthritis in skeletal remains have been extensively studied (e.g., Jurmain, 1990; Kahl and Smith, 2000; Merbs, 2001; Šlaus, 2000; Webb, 1989; Weiss, 2005, 2006; Weiss and Jurmain, 2007). Sex differences are frequently attributed to differences in activity patterns. For example, Derevenski (2000) examined 110 adults from Ensay and Wharrem Percey, UK from the 16th to 19th Century and found that the sex difference was less pronounced in the Ensay sample than the Wharrem sample. Furthermore, Derevenski found that females had more severe vertebral osteoarthritis, especially in the Ensay population, than did males, which she attributed to use of creels (a form of basket) by females in these populations to carry heavy loads. Another example comes from Šlaus (2000a) who examined a skeletal sample of 104 individuals from the 14th to 18th Century. She found that, in her age-controlled sample, males had higher degrees of osteoarthritis in all joints and significantly higher degrees of osteoarthritis in vertebral joints than females, which she attributed to sex differences in activity patterns supported by ethnographic data. Finally, a smaller study by Lovell and Dublenko (1999) studied five individuals from the fur trade in 19th Century Canada. The osteoarthritis in the males, they suggest, is related to their hard labor of lifting, paddling, and other activities; the osteoarthritis in the female may have been a result of the activities involved with non-mechanical horticulture.

Sex differences, on the other hand, may also be caused by differences in body size and hormonal differences (Waldron, 1997; Weiss and Jurmain, 2007). It is noted in the medical literature that heavier people have more severe osteoarthritis than lighter people (Tepper et al., 1993; Heliövaara et al., 1993). The medical literature also has shown that females tend to have slightly higher levels of hip osteoarthritis, which may be linked to female hormonal changes and genetics (Wilson et al., 1990). Weiss (2005b) has found that, although upper

limb osteoarthritis scores have no correlation with body mass in a sample of 77 individuals from two sites (a Euroamerican sample and a British Columbian Amerind sample), there is a correlation in lower limbs and it appears that smaller individuals had greater arthritis scores than did larger individuals. Weiss (2006) found the same trend of a negative correlation with hip arthritis and body mass in a prehistoric California Amerind sample of 114 individuals. Weiss's (2005b, 2006) findings seem to contradict the clinical literature on weight. Body size as measured on skeletal remains, however, is not body weight and it is unlikely that the individuals in this sample were overweight. It could be that the smaller the linear size of an individual, the smaller their joints and that, if they add extra pounds to their frame, this would affect a smaller individual more than a larger individual. The difference between the medical literature and the anthropological literature may reflect the phenomenon that high body mass index (obesity and being overweight) seems to be a modern phenomenon. Thus, the effect of body mass may not be as significant an issue for anthropologists looking at pre-modern samples as it is for contemporary populations.

Finally, it is important to mention once again that osteoarthritis seems to be highly heritable, which means that individuals doing the same activity may actually have different arthritis rates (Weiss and Jurmain, 2007). Additionally, anatomical variance, such as longer shinbones, can create more mechanical loading and increase osteoarthritis rates (Weiss and Jurmain, 2007). However, there are some joints that are more useful in reconstructing activity patterns, such as the upper limbs rather than the lower limbs and back. There are some joints that are under less control by genes compared to other joints and are often not weight bearing; anthropologists need to concentrate on the less innate arthritis joints, such as the shoulder joint. Although spinal (vertebral) osteoarthritis scores are confounded by genes, vertebral stress fractures seem to be free of these confounds.

3.6. STRESS FRACTURES AS ACTIVITY INDICATORS: VERTEBRAL COLUMN TRAITS

Schmorl's Nodes

Schmorl's nodes are herniations of intervertebral discs that are often associated with trauma, especially in the thoracic and lumbar vertebrae (Figure 3.12). In the medical literature, acute trauma has been pointed out as one cause of Schmorl's nodes; however, other origins are possible, such as repetitive strains. Faccia and Williams (2008) also point out that Schmorl's nodes are linked with patient reported back pain and, thus, this should be considered when reconstructing life quality of past populations. Anthropologists use Schmorl's nodes as indicators of stress and activity in order to understand past lifestyles, such as sexual divisions of labor and social status (e.g., Jiménez-Brobeil et al., 2009; Robb et al., 2001; Šlaus, 2000; Sofaer Derevenski, 2000; Wentz and Grummond, 2009). For example, Wentz and Grummond (2009) examined two teen skeletons from the Ukraine dated to 325 BC and found extensive healed fractures and Schmorl's nodes, which they tied to horseback riding and their warrior class. Jiménez-Brobeil and colleagues (2009) also examined Schmorl's nodes in relation to activity patterns; their sample consisted of Bronze Age (1800–1300 BC) Spaniards of an elite class. They found that Schmorl's nodes do not relate to age

and that the thoracic vertebrae are most likely afflicted. The sample also had a great sex difference with 56% of males having nodes while only 30% of females were afflicted. This difference, the authors argue, is due to the strenuous lifestyle of the males who engaged in mining, livestock care, and sword fights (as indicated by their funerary goods). However, as anthropologists learn more about the etiologies of osteoarthritis, muscle markers, and cross-sectional shape, all of which are confounded by non-activity related factors, reconstructing activity patterns is becoming more difficult and less promising (e.g., Weiss, 2003, 2004, 2005b; Weiss and Jurmain, 2007).

Thus, Weiss (2005c) decided to examine whether Schmorl's nodes may also be a condition anthropologists frequently use as indicators of past activities that are correlated with non-activity related factors. She tested whether Schmorl's nodes are correlated with age, body size, spinal osteoarthritis, and sex to determine whether the etiology of the nodes is affected by non-activity related factors in a skeletal sample of 77 individuals ranging from 18 years of age to 69 years of age. Schmorl's node frequency in a population of Quebec prisoners of war known for heavy load carrying and harsh farming labor is compared with the Schmorl's node frequency of a highly active, yet not necessarily "back-breaking," British Columbian Amerind population.

The British Columbian Amerinds come from archaeological coastal sites dating from 3500 to 1500 years BP (Cybulski, 1992); these individuals belonged to a hunter-gatherer population where males hunted for small marine mammals and other game inland, in addition to fishing. Females gathered berries, crabapples, and starchy roots to supplement their diets (Cybulski, 1990, 1992). The Euroamerican skeletal remains come from English prisoners of war who died after being captured by French Canadians in Quebec about 200 years ago (Cybulski, 1988; Piedalue and Cybulski, 1997). Prior to their imprisonment, many of these individuals were farmers in the region and engaged in hard manual labor while farming. Some of these individuals trained to fight in war and, hence, were likely required to participate in long marches, extensive physical training, and carrying loads. While prisoners, they were required to participate in hard labor, carry heavy loads, and undertake long marches while imprisoned, which placed high strains on the spine (Piedalue and Cybulski, 1997). 18.5% of British Columbian Amerinds had Schmorl's nodes and 61% of Quebec prisoners of war had Schmorl's nodes. No correlation with age, sex, and body size existed with Schmorl's nodes. Additionally, the Quebec prisoners of war who had a history of spine-straining activities have far more Schmorl's nodes (even though they do not have greater spinal osteoarthritis scores) than the British Columbian Amerinds, which suggests that the Schmorl's nodes are related to the actions that caused strain on the back, such as heavy load carrying and farming. It is important, however, to remember that the Schmorl's node frequency could be related to acute traumas associated with the type of labor performed. Another important consideration is that, in the medical literature, Schmorl's nodes seem to be more often formed in younger individuals due to the weakness of the epiphyses (e.g., Chandraraj et al., 1998); consequently, activities later in life may not be represented in reconstructions using Schmorl's nodes as indicators of activity.

Üstündağ (2009) replicated some of the above findings on Schmorl's nodes with a large sample of over 400 individuals from a 16th to 18th Century Austrian site. Üstündağ found that Schmorl's nodes were most likely to occur in thoracic vertebrae, which he links to thinner discs and torsional stresses, and that the nodes do not correlate with age or osteoarthritis in the spine. In the Austrian sample, males had more Schmorl's nodes than females, which was

likely due to heavy work loads by males, but Üstündağ provides a word of caution and states anthropologists should attempt to find samples where the sex difference is reversed.



Figure 3.12. Schmorl's Node. In a male lumbar vertebra. Photo taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.

Spondylolysis

Spondylolysis is a condition of the spine that refers to a separation of the vertebral arch from the vertebral body and excludes the lack of fusion of the spinous process (Figure 3.13). Merbs (1996a) discussed the role bipedality plays in spondylolysis; typical spondylolysis (limited to the lumbosacral region) is absent in nonhuman primates and in children too young to walk. Spondylolysis, however, must have supplementary causes since the percentage of individuals with spondylolysis ranges from less than 5% in populations, as such Native American remains from the Columbia River region (Congdon, 1932) to over 50% in Eskimo populations (Merbs, 1995, 1996a, b).



Figure 3.13. Spondylolysis in a California prehistoric Amerind. Posterior view of fifth lumbar from an adult male showing complete bilateral separation. Photo taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.

Clinicians link the appearance of spondylolysis to activity patterns. In the sports literature, clinicians find higher spondylolysis rates than population norms in gymnasts (Commandre et al., 1988), rowers (Rumbal et al., 2005), weightlifters (Risser, 1991), rugby players (Iwamoto et al., 2005), soccer players (Rassi et al., 2005) and other athletes (see Shrier, 2001 for a summary). Recent studies also link spondylolysis to sports that require extensive use of one upper limb side, such as cricket, baseball, and tennis (Ruiz-Cotorro et al., 2006). Many of these activities involve hyperextension of the hip and torsion of the back, such as in swinging a bat and throwing a ball. Only individuals with back pain are likely to be examined for spondylolysis and, thus, spondylolysis rates may be under reported. Anthropologists, too, have documented spondylolysis and correlated it with various activities. Anthropologist Arriaza (1997), for example, connected the lifting or moving heavy objects with spondylolysis, such as moving large stone pillars in Guam, and Patricia Bridges (1989b) tied spondylolysis to non-specific activities related to hunting and gathering. Merbs (1996b, 2002) noted that the high percentage of spondylolysis in Arctic populations is related to heavy labor required to live in those cold climates, such as lifting heavy items, kayaking, paddling, and wrestling.

Some patterns of spondylolysis occur regardless of activities and cultures. Age patterns have emerged in spondylolysis studies; spondylolysis does not afflict individuals too young to walk (e.g., Fibiger and Knüsel, 2005; Merbs, 1996a, b), which relates to the necessity of

stresses plus bipedal behavior. Clinical studies of modern populations record young individuals afflicted by spondylolysis, which one may attribute to adults reducing their sports activities compared to juveniles and young adults (e.g., Shrier, 2001). Another interesting twist is that, as individuals grow very old, spondylolysis seems to decrease; Merbs (2002) noted the decrease in spondylolysis rates in older adults could relate to the healing of fractures and, thus, prior spondylolysis escapes detection. However, Bridges (1989b) found an increase in spondylolysis frequency in older females in southeastern Archaic Amerinds, which she suggested relates to osteoporosis and degenerative joint disease. Most studies on spondylolysis find higher frequencies in males (e.g., Arriaza, 1997; Fibiger and Knüsel, 2005; Weiss, 2009b). Sex differences have most often been related to activity pattern differences between males and females. An example comes from Arriaza (1997) who looked at a population in Guam and found higher rates of spondylolysis in males than in females, which he related to males moving large stone pillars. In California hunter-gatherers, males had more than twice the rate of spondylolysis than did females (26% and 11%, respectively). Activity patterns, such as thrusting and throwing shafted obsidian points, could explain the sex differences (Weiss, 2009b). An exception with well-documented ethnohistorical evidence comes from studies on the northeastern Nebraska Amerinds; females were responsible for hide scraping, house construction, and gathering firewood (Reinhard et al., 1994). In this population of Nebraskan Amerinds, females had greater spondylolysis frequencies than did their male counterparts (Reinhard et al., 1994). As mentioned above, sex differences are often attributed to activity patterns, but biological sex differences associated with anatomical differences may be present as well that predispose males to spondylolysis at a greater frequency than females. Although questions have arisen whether anatomical variation and genetic disposition may explain spondylolysis patterns, currently many of the trends found in the bioarchaeological record are best explained by activity patterns (Weiss, 2009b).

3.7. Miscellaneous Other Methods to Reconstruct Activity

There are a few other methods anthropologists have used to reconstruct activity patterns; some of these methods have lost their popularity while others have been re-utilized for other purposes. Bone histology, for example, was once a common way to reconstruct activities (see Larsen, 1997); bone histology studies looked at osteon (bone cell) density and size. Anthropologists argued that many small bone cells seemed to indicate high stress caused by activity and good bone turnover rates; whereas larger osteons were a sign of low turnover rates since the size of osteons increases over time. Recently, however, the validity of using osteon size and number as an indicator of activity has been questioned. Hedges and colleagues (2007) noted sex and differences in turn over rate that seem to be biological in nature; females bone turnover decreases about 3-4% a year from 20 to 80 years of age and for males bone turnover decreases about 1.5-3% a year in the same ages. Additionally, young adults have increased bone turnover rates. These differences suggest that age is much more important in osteon size and density than are activities. Additionally, Peck and Stout (2006) noted much variation in bone mass within an individual in a sample size of 41. They suggested that this variation was due to specific mechanical loads and not dependent on age or sex, but Pfeiffer and colleagues (2006) found the opposite results in a sample of 44

Holocene South Africa remains when examining rib and femoral samples. Thus, whether osteon size and density are due to specific mechanical loads or rather a result of age, sex, and nonspecific remodeling is still up for debate.

Metric analyses have also been carried out by anthropologists attempting activity reconstructions. The data is usually taken as measurements of minimum and maximum shaft diameters. These measurements are easy to take and do not require the expensive tools that cross-sectional analyses may require; however, external measurements cannot be used to calculate the more useful cross-sectional properties of moments of inertia and polar moments of inertia. Anthropologists have concluded that total area, which is what one measures with a caliper, is the least useful of the geometric properties in reconstructing activity patterns (e.g., Weiss, 1998, 2005; Ruff, 2000). Metric measurements, however, can be utilized to reconstruct body mass that is required for standardizing cross-sections and controlling for body mass in muscle marker studies. Therefore, sometimes there is no substitution for x-rays or CT-scans of limbs to get cross-sectional data.

3.8. Chapter Summary

In recent years, reconstructing activity patterns has been a major research area in bioarchaeology. The many ways in which anthropologists have attempted to understand past people's cultures and activities rely on two main principles: bone remodeling theory, which was first discussed by Julius Wolff and is sometimes referred to as Wolff's Law, and wear-and-tear theory. Bone remodeling theory is invoked when using cross-sectional analyses and muscle markers. Wear-and-tear has been proposed for osteoarthritis and spinal stress fractures. Although clinical, sport, and experimental research have demonstrated that bones do remodel when stressed and that use of joints do wear down after use, we have also found that there are many confounds to implementing the skeletal markers of activity to reconstruct what people were doing in the past. Some of these confounds are genetic, such as the high degree of genetic influence in spinal osteoarthritis frequencies. Other confounds can be more easily controlled for, such as the muscle marker and body size confounds, even though sex differences seem to be intrinsically embedded in the body size and muscle marker dilemma. And yet, still there are confounds related to data collection: spondylolysis for example seems to be prevalent in past peoples with labor intensive cultures, but whether the prevalence of spondylolysis is high in living populations is difficult to surmise since it may be underreported if it causes no pain.

Nevertheless, anthropologists are getting better at teasing apart the data to understand what activity markers truly tell us. We now understand that, in order to reconstruct the past, muscles need to be considered in groups since the muscles work in groups; aggregation is a useful tool in muscle marker research. Additionally, we can be certain that Schmorl's nodes are related to activity (and sometimes acute trauma) since the clinical literature has a good record of back pain associated with these herniations and there are no sex, age, or body size confounds with Schmorl's nodes. Asymmetry of cross-sectional analyses also has helped to determine whether bone remodeling takes effect after adulthood and we have evidence that asymmetry increases due to activities, such as spear-throwing, and decreases with bimanual activities, such as grinding corn. With osteoarthritis, research has demonstrated which joints

are most useful for reconstructing activity patterns; upper limb osteoarthritis and upper limb osteoarthritis asymmetry shows great promise in helping us to reconstruct the past.

Future studies may tend to use more technology to fine tune data collection, but in the end we must figure out which traits are crafted by activities and which are determined by biology. Anthropologists using evidence from a variety of research fields have taken on this challenge and will likely prevail with better reconstructions forthcoming.

Key Terms

Activity Patterns
Asymmetry
Bone Remodeling
Compression
Cortical Area
Cross-sectional Geometry
Force
Moments of Inertia
Muscle Markers
Osteoarthritis
Spondylolysis
Schmorl's Nodes
Strain
Stress
Torsion
Wolff's Law

Chapter Questions

- 1) What are some of the traits anthropologists use to reconstruct activity patterns?
- 2) What confounds can be detected in these traits that hinder activity reconstructions?
- 3) What universal patterns are found when examining traits used for activity patterns?
- 4) What activities have been linked to spinal stress fractures?
- 5) How does asymmetry help anthropologists reconstruct activity patterns?

Chapter 4

HEALTH AND DISEASE: UNDERSTANDING MORBIDITY FROM THE SKELETON

4.1. INTRODUCTION TO DISEASES OF THE PAST COMPARED TO THE PRESENT

One of the interesting paradoxes bioarchaeologists face is that the medical (clinical) literature of the present day industrialized nations note a variety of diseases that are never or rarely seen in the skeletal remains examined from archaeological sites. Some of the differences in disease types and frequencies are related to the difference in examining a whole individual compared to just the skeletal remains; for example, arteriosclerosis (hardening of the arteries) is a common problem in the elderly in Europe and the US, but is never found in skeletal remains due to the lack of arterial data. Interestingly, however, mummies of ancient Egypt who were old at death (e.g., Ramses II) showed evidence of arteriosclerosis suggesting that even though medical experts attribute the disease to modern lifestyle it is possible the frequency in prehistory was similar in elderly individuals and the absence relates to a lack of data and lack of longevity in many prehistoric populations. Another aspect of disease comparisons is that lifestyles, technologies, and medicine have changed and, thus, deadly ailments of the past can now often be treated. Infections of all sorts were killers in great numbers in prehistory; dental infections may have killed more people over the last 10000 years than any other disease. Many infections are now treatable with antibiotics, but antibiotic resistant forms are making infections deadlier once again. Finally, dietary and other nutritional deprivation (e.g., iron deficiency anemia, vitamin D deficiency rickets, and osteomalacia) are prevalent in skeletal remains from many archaeological sites; these deficiencies are nearly unheard of in modern industrial First World societies, although questions of their return due to poor diets and overzealous sun protection have arisen. And, dietary deficiencies are abundant in developing nations.

The next couple of sections will address the types of features anthropologists identify on skeletal remains to determine health of past populations; these features can be divided into two groups: general indicators of stress (e.g., Harris lines, stature, enamel hypoplasia, bone mass, and tooth size) and specific indicators of stress (e.g., rickets, osteomalacia, cribra orbitalia, porotic hyperostosis).

4.2. GENERAL INDICATORS OF STRESS

General indicators of stress include stature, vertebral canal size, enamel hypoplasia, tooth size, Harris lines, and bone mass. General indicators of stress on the skeletal system can reveal to a researcher how healthy a population was or how often they recovered from environmental stresses. For example, although Harris lines and enamel hypoplasia are often introduced and discussed as signs of poor health, they may actually be signs that individuals recovered from the stress while less robust individuals perished. Below I explain some general stress indicators prior to discussing these indicators in regards to current literature that use multiple indicators to best reconstruct the population's health.

Vertebral neural canal size is an interesting stress indicator since the canal forms by age four and the vertebral body grows till early adulthood; thus, a small canal is indicative of early childhood stress and yet can be seen throughout an individual's life. Vertebral neural canal size, unlike some other stress indicators such as stature, is rarely reported independently and the literature that uses this trait will be discussed below. Enamel hypoplasia is similar to vertebral neural canal size in that it indicates stress early in life (from 4 months in utero to 12 years of age), but will be present throughout one's life.

Enamel hypoplasia is noted as visible grooves on the anterior teeth (e.g., canines and incisors) and to a lesser degree on the premolars and molars (Figure 4.1). The lines present on the teeth correspond to specific age periods when the stress occurred since tooth formation and eruption is under tight genetic control. Furthermore, teeth do not remodel and thus the lines from enamel hypoplasia are always present and do not fade with age. The actual width of the line may suggest duration of stress, and some trends have been noted in the archaeological record, such as an increase in lines with the transition from hunter-gatherer to agricultural societies and a correlation of enamel hypoplasia line locations with age at weaning (Larsen, 1997). In some populations (e.g., Keenleyside, 2008), a decrease in longevity has been correlated with individuals who have enamel hypoplasia and smaller tooth size (Larsen, 1997).

A commonly used general stress indicator is the presence of Harris lines. Harris lines are opaque horizontal lines on long bones due to a cessation of growth and a resumption of growth. They are most often seen on the tibiae (shin bones) and are only visible on x-rays. The lines may fade with age due to bone remodeling and, thus, may not always be a good indicator of stress in adult samples. Additionally, in living populations some healthy children have Harris lines and some undernourished children have none. Arctic populations, as a rule, seem to have seasonal Harris lines relating to the lack of sun and scarcity of resources. The occurrence of these lines in life starts at 6 months of age and peaks at 5 years of age (Larsen, 1997). Inclusion of Harris lines as stress indicators usually occur in studies that also examine enamel hypoplasia, stature, and other stress indicators.

Stature, which is taken from long bones, can be used as an indicator of health when used in comparison studies. Many studies use stature to assess health either in conjunction with other traits or as the only trait examined. Furthermore, stature for modern populations is well documented and trends for the last couple hundred years have been calculated. In general, height or stature has increased over time and is usually associated with continuous uninterrupted growth. We see in modern populations that some of the healthiest and wealthiest of populations (e.g., Northern Europeans) are also some of the tallest, whereas

Third World Nations often are populated with shorter individuals. Some stature differences will surely be genetic, but the increases in stature in East Asians, for example, demonstrate how greater caloric intake and fewer infectious outbreaks can lead to taller people without genetic shifts. Recent research on stature as a way to reconstruct past populations' health has given insight to the effect of urbanization of European children.

A 2008 article published on Portuguese remains dating from the Mesolithic (5210–4950 BC) to the late 20th Century highlights the shifts in stature within genetically similar populations that relate to environmental changes. Cardoso and Gomes (2008) examined 200 individuals and found that stature trends can be documented and explained even with this relatively small sample. Stature slowly increased from the Mesolithic period until the Middle Ages (which occurred around from around 1060 to 1485 AD). Thus, even though earlier studies found a decrease from the Mesolithic period to the Neolithic period, Cardoso and Gomes did not find evidence for this decline. The decline in stature from the end of the Middle Ages until the late 19th Century in Portugal may be related to an increase in population density and the growth of urban centers. Throughout time, increases in population density and urbanization is often linked with decreases in health due to increased illness from lack of sanitary methods, overcrowded conditions, and poor nutrition. Rural populations often are buffered from nutritional deficiencies when they do not overuse a staple food source. In Portugal, this negative trend in stature was not reversed until 1960s or 1970s when economic revival brought about food refrigeration, cheaper food sources in the urban environments, public health and sanitation improvements that included sewer systems and running water, and welfare and medical care for the populations.



Figure 4.1. Enamel hypoplasia. Photo taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.

Catch-up growth can result in individuals who were temporarily under stresses (such as due to a childhood illness) to retain normal height as an adult; thus, short statures are usually the result of long term or repeating assaults from the environment. Recent research on stature in the bioarchaeological literature confirms the importance of stature as a skeletal stress indicator, but also notes that catch-up growth can hide childhood stress. In another Portuguese study, Hugo Cardoso and Susana Garcia (2009) point out that the living standards in the urban city of Lisbon, which had child labor until the 1960s in their industries, may have prevented the catch-up growth during adolescence that less-urban children experienced after their assaults from the environment. As such, people from Leira in Portugal during the Medieval period grew to have normal adult statures, whereas people who grew up in Lisbon as late as the 1950s were shorter. Many children went to work starting at age twelve and as a result reduced their time spent outside and their nutritional and caloric intake, while the Leira children did not enter the workforce. Sometimes, location is more important than the temporal period. Additionally, McEwan and colleagues (2005) reported that in a sample from Wharram Percy, a British medieval site, juvenile bone length measurements were on average the length of individuals 4 years younger than their age; thus, a 16-year-old was as tall as a 12-year-old modern Briton. Nonetheless, individuals who grew up to their adult years were only slightly shorter than modern British people. Thus, either individuals who died young were those that were the most stressed or the individuals who lived to adulthood experienced catch-up growth.

Many studies that examine health use multiple indicators. Research published on Upper Paleolithic populations has called into question the presumption that agriculture started the decline of health in prehistoric populations. Anthropologists Holt and Formicola (2008) point out that from the Early Upper Paleolithic to the Late Upper Paleolithic (all before agriculture set in) there is a decrease in stature, an increase in Harris lines (from 33% to 48%), and an increase in enamel hypoplasia (from 16% to 29.4%). Although the samples from both period are overall healthy, there seems to be a decrease in health that may be the result of climate shifts (warming trends that effected animal herds) or population increases.

A 2001 Polish study noted interesting patterns in two medieval sites that included one high socioeconomic status group and one low socioeconomic group. With a sample of over 200, anthropologist Rewekant (2001) found that females seemed to be more buffered from environmental stresses. The female advantage has been touted previously as related to the necessity of having healthy females to bear and rear children. She also found that individuals with small vertebral neural canals (a stress indicator at 4 years of age and younger) had lower bone mass (a stress indicator in adulthood). This may indicate that individuals experienced stress throughout their lives or that those who were susceptible to stress in their early years were susceptible to stress later on as well. Medical literature supports that stress during childhood can negatively affect adult health even when the stress was of fairly short duration.

In 2009 a study of 84 individuals from Botswana African dating from 700 to 1300 AD were examined by anthropologists Mosothwane and Steyn who found that overall the sample seemed healthy; the individuals had few signs of cribra orbitalia (usually a sign of anemia or iron deficiency), enamel hypoplasia, or other stress indicators. The peak of enamel hypoplasia occurred at 4 to 5 years of age (later than the usual 2-3 years that is found when most populations wean their children off of breast milk). The shift in enamel hypoplasia age may be due to different weaning practices. Interestingly, 53 individuals were under 15 years of age, thus the health of these people may be artificial and they could have died prior to

recovery from illness (which would be why there are low levels of stress indicators). Many times, anthropologists find it difficult to diagnose causes of death since pathologies that are of short duration but fatal often leave no trace of their presence on bones.

As you may notice by now, most skeletal stress markers are indicators of how the environment affected sub-adults. There is, however, one way to tell the stress of adults during their adult years: bone mass. Bone remodels throughout life, which was described in chapters 2 and 3, but as one ages, bone remodeling shifts to continuous resorption of bone (at the endosteum) and a decrease in bone deposition (which occurs in adults mainly at the periosteum). This disequilibrium in bone deposition and resorption results in a lower bone mass density and a thinner cortical layer with an increase in the medullary cavity. These changes are referred to as osteopenia and osteoporosis. Osteoporosis can be defined as a decrease in bone mass and deterioration of bone tissue, both of which decrease bone strength and can increase fracture susceptibility. Osteopenia is less severe than osteoporosis. Often in the bioarchaeological record, it is only when there are vertebral collapses (Figure 4.2), radial fractures (Colles' fractures; Figure 4.3), or hip fractures found in association with bone loss that the loss is defined as osteoporosis and not osteopenia (Zaki et al., 2009). Osteoporosis can be divided into a variety of types. When osteoporosis is not associated with a distinct genetic disorder, then it is referred to as primary osteoporosis or idiopathic osteoporosis (Zaki et al., 2009). Within idiopathic osteoporosis there are two types: I and II. Type I affects post-menopausal females (usually starting around 45 years of age) and is typically characterized by trabecular loss with an increase in fractures of the above mentioned type. The reason for this sex-specific osteoporosis is because hormonal shifts associated with menopause affects bone deposition. Type II osteoporosis is related to age and is found in both males and females. Bone loss extends to the cortical bone as well as trabecular bone, which leads to an increased rate of fractures of the hip. Although the decrease in bone mass is part of the natural aging process, environmental stresses (such as protein deficiency and excessive physical strain with low calorie consumption) can exacerbate the problem. Additionally, environmental influences, especially when comparing across time periods or cultures, can reveal stresses adults experienced. Interestingly, clinical data and skeletal data differ in types of fractures that are most commonly diagnosed. In the bioarchaeological record, vertebral collapses are most common. In the clinical data Colles' fractures are more common, followed by hip bone fractures (which are the most severe). Low frequencies of vertebral collapses in the clinical literature is likely due to the fact that these are the least serious and often people do not realize that the bone has collapsed; they may or may not result in back pains (Brickley, 2002). Thus, the osteoporotic individuals are less likely to go to the doctor for these fractures.

A brief review of the bioarchaeological literature on bone loss highlights interesting trends and contradictions. Most studies examine bone loss through dexagrams, x-rays, and CT-scans; common bones studied are the metacarpals, vertebrae, and femora. Often, fracture patterns are also noted with special attention to radii, femora, and the vertebral column. In Egypt, during the pyramid building era of the Old Kingdom, osteoporosis was present in both males and females (Zaki et al., 2009). It appears that, when examining males and females from the working class and high officials, there are some interesting sex and class differences that may be explained by activity and diet. Females lost more bone than males, and female workers had greater bone mass than female high officials. The female workers may have been better off due to the physical activity they engaged in, but this activity did not help the males. Male officials had more bone mass than male workers, which the authors suggest may relate

to excessive physical labor (erecting those Giza pyramids) and the low quality of food available to workers. Additionally, Nubian populations have high frequencies of osteoporosis, especially at young ages, which may be due to an over-reliance on millet (Foldes et al., 1995).



Figure 4.2. Vertebral collapse in a female skeletal individual from a prehistoric California population. Photo taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.



Figure 4.3. A likely Colles' fracture. Photo taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.

Femoral cross-sections from 66 individuals from Northeast Italy during 730 AD showed signs of osteoporosis with a steady decline in bone mass (this was more apparent in females) (Drusini et al., 2000). Additionally, no fractures were found, which suggests that the bone mass was less severe than in other areas. Mays and colleagues (2006) examined fractures and bone loss in Norway (N = 129) compared to a United Kingdom sample (N = 129). It was well known that modern differences in osteoporosis exist, but whether these differences were already present in medieval populations had yet to be tested. They found that in medieval populations no differences existed in bone mass between the two populations, but the Norway sample had a greater frequency of fractures. These differences in fracture frequency may relate to the icy climate of Norway that increases the chances of falling combined with falling on hard ice, rather than the soft earth enjoyed by the rural population examined in the United Kingdom. Thus, environment affects fracture frequencies. Another study of Norway skeletal remains looked at 36 prehistoric remains (5000 BC–800 AD), 38 Viking remains (800–1050 AD), and 145 medieval remains (1050–1536 AD) to determine bone loss patterns (Holck, 2007). Anthropologist Per Holck also took into consideration rural versus urban living conditions and whether the individual was part of the normal society or the monastery. Finally, he compared their data to modern Norwegians. Holck found that there were no differences between earlier populations and modern populations; an unexpected finding since previous populations engaged in more activities. Within the medieval population, the monastic individuals had the greatest bone mass density, which again was unexpected since they were thought to be the least active (but perhaps they ate the best foods and were protected from other environmental stresses). Holck, as well as others, mention difficulty in comparing modern samples to bioarchaeological samples since age is not precise in bioarchaeological samples. Furthermore, taphonomy (what happens from burial to discovery) could affect bone density.

In England, osteoporosis findings occasionally also buck common trends. For example, anthropologists Agarwal and Grynepas found that in 58 individuals from the 11th to the 16th Centuries AD, no sex differences were present in bone mass at old age (even though male bone loss decreased slowly and female bone loss occurred rapidly with a stasis of loss in later years). Thus, bone loss occurred in females less than expected and females lost most bone mass prior to menopause rather than afterward. The authors attributed this early onset bone loss to lactation stresses coupled with nutritional deficiencies. Excessive activity in females, which included domestic and farming activities, may help explain the lack of sex differences as well. Another study from the same population found that, although modern Englanders have lifestyles that should increase bone loss (i.e., low levels of activity, smoking, and drinking) medieval Englanders had greater bone loss (Mays et al., 1998). Again, perhaps lactation helps explain this difference, since the medieval females likely gave birth more often and breast fed for longer periods of time. Another possibility is that body fat seems to protect females from osteoporosis and, therefore, the low level of body fat in medieval females may have been detrimental in terms of bone health (Mays et al. 1998).

A study of bone mass from 3rd to 4th Century Britons examined metacarpals of 39 females and found that patterns of bone loss in these individuals did mirror the patterns found in modern populations, but that the loss was greater in the 3rd to 4th Century population (Mays, 2006a). The excessive bone loss (coupled with fractures of the radius, hip, and vertebrae, which all occurred in the 50+ age group) seems to be attributable to either genetic inherent susceptibility or environmental stresses, such as vitamin D deficiency or protein deficiency.



Figure 4.4. Cross-sectional changes due to drought: Cemetery 1 (Left), pre-drought period; Cemetery 2 (Right), drought period. CT scans taken at UC Davis, courtesy of Elizabeth Weiss.

Sometimes stress can come from environmental factors, such as droughts. Jones, et al, (1999) appeared to find an increase in violence, traumatic pathologies, cortical bone disease, malnutrition, and mortality in California from 1450 to 600 years ago that coincided with a major drought. Weiss (2002) examined remains from two cemeteries that encompassed the pre-drought period and the drought period. She found that in a skeletal sample of 98 individuals, lifespan decreased by 7% (from 33.51 to 31.28 years of age), trauma increased 14% (from 48% affected to 62% affected), and that femoral cortical thickness decreased by 17% (Figure 4.4). Thus, it appears that general stress indicators that positively correlated with the drought and cortical bone, as well as other traits, can be used to understand whether the environmental changes caused changes to the population's well-being even when only examining adults.

4.3. SPECIFIC INDICATORS OF STRESS

Vitamin D Deficiency

Specific indicators of stress include rickets, osteomalacia, cribra orbitalia, and porotic hyperostosis. Rickets and osteomalacia are both related to vitamin D deficiencies. Vitamin D is actually a hormone that resides in your skin and is activated by sun exposure (Pitt, 1988). It functions to absorb calcium (which is obtained through diet), and calcium is required to mineralize osteoids (which are pre-bone cells that are not yet mineralized). Throughout one's life, bone remodels (see chapters 2 and 3) and heals from fractures. In addition, bone growth early in life requires much mineralization of bones. Another conundrum is that, when calcium is not absorbed the body sends signals to bone cells to increase resorption of bone and, as a result, the problem of weak bone is exacerbated when vitamin D deficiency occurs (Mankin, 1974). Thus, during an individual's life vitamin D is essential to maintaining strong and healthy bones. The only natural source of vitamin D activation is through direct contact with

sunlight. Other sources of vitamin D are found in extremely small doses in eggs, milk, liver, and oily fish (salmon and sardines) and their liver oils. Interestingly, however, the amount of vitamin D found in these food sources varies depending on seasonal variation (likely due to the sun exposure of the foods) (Pitt, 1988; Holick 2003). Vitamin D deficiency as diagnosed is divided into rickets (which is when the condition is found in sub-adults) and osteomalacia (which is when the condition is found in adults).

Rickets manifests itself in deformity of the lower limb bones (bowing of legs) (Figure 4.5) and deformation of the pelvic bones (hip) due to the lack of weight-bearing ability of the unmineralized bone. This can lead to difficulty in childbirth, increased risk of fractures, and related problems (such as infections due to fractures). Rickets is not often found in the skeletal remains of individuals who resided in sunny climates, which is not surprising since sunlight activates vitamin D. However, where we do see rickets in great numbers is in the United Kingdom when industrialization began in urban areas. Mays and colleagues (2008), for example, examined a skeletal sample of 287 individuals and found bowing of legs, reduction in stature, and deformed pelvises in young individuals in 19th Century Birmingham, England. This area was at the center of the Industrial Revolution, and the levels of air pollution, coupled with child labor and the already gray skies of England created an endemic rickets problem, which may have led to the death of these subadults who were aged from 2 to 6 years of age. These individuals seemed to have recurring signs of rickets, which was determined in part by the fact that the older children were shorter for their age than younger individuals (mainly as a result of bowing in the thigh bones). Across the Atlantic, vitamin D deficiency also arose, this time African-Americans in the early 19th Century were the victims of rickets. Skeletal remains of children excavated at Philadelphia's First African Baptist Church showed an abundance of rickets likely due to the industrial smog of Philadelphia coupled with low levels of sunlight and a population of Africans who were adapted to sun protection via dark skin, which reduces vitamin D activation (Rankin-Hill, 1997). The dark skin would have been essential to prevent folate destruction in the African climes these people were evolved for; destruction of folate can lead to increases in congenital birth defects. However, vitamin D deficiency is not just a problem for children – adults can have bone health difficulties as well.

Osteomalacia is the term used for vitamin D deficient bone problems in adults. The manifestation of osteomalacia includes curved sacra, collapsed vertebral columns (kyphosis), unhealed fractures (known as Looser's zones), and pelvic deformities. Problems can be exacerbated if individuals had rickets as children. In a study by Brickley and coworkers (2005), osteomalacia is diagnosed in the Galler collection, which is housed in Geneva Switzerland, and in the Federal Museum of Pathological Anatomy, which is housed in Vienna Austria. The sample of individuals with osteomalacia out of thousands of individuals was 28. These individuals came from 19th Century and early 20th Century remains. Interestingly, the authors point out that, although rickets is found in England and other industrial revolution sites (likely related to urban smog, naturally gray skies, and increased time spent indoors in factories), osteomalacia is rarely reported in the archaeological record. To date, as pointed out by Brickley and colleagues, only a handful of osteomalacia cases have been published in the bioarchaeological literature. These include two post-medieval sites in London (Molleson and Cox, 1993, and White, 1985, as cited in Brickley et al., 2005) and possible fragmentary evidence from Nubia and Egypt (Ortner, 2003), and a Roman pelvis (Boylston and Roberts, 2000). This lack of osteomalacia may be due to the difficulty in diagnosing the deficiency in

skeletal remains since the same features mentioned above can also relate to osteopenia or osteoporosis (which are age-related bone losses). In clinical settings, osteomalacia can be distinguished from osteopenia or osteoporosis by taking chemical tests for calcium and vitamin D levels. Another difficulty Brickley and colleagues mention is that osteomalacia increases chances of bones being fragmented upon discovery. Nonetheless, their hope is that, by including more specific features to look for, one can try to distinguish age-related bone loss from osteomalacia.



Figure 4.5. Rickets in a young individual. Image created by Michael L. Richardson, M.D. Sept. 28th, 2004.

Iron Deficiency

The other indicators of specific stress are cribra orbitalia and porotic hyperostosis, both of which are related to iron deficiency anemia. We get iron from consumption of meats (plants are not a good source of iron as, even when they are full of iron, the body cannot absorb the plant iron well and some plants with iron will even inhibit the absorption of other irons). Iron is necessary for bringing oxygen to blood and body tissues. Basically, iron deficiency can delay normal motor function and cause problems for normal thought processes, decreases the ability to work and move, and can even effect the functioning of vital organs. Iron deficiency (also known as anemia) can arise from several factors. Dietary factors are often implicated, which are related either to deficient meat consumption, excessive consumption of foods that inhibit absorption of iron, or a combination of the two. Additionally, vitamin C enhances iron

absorption so a lack of vitamin C may cause anemia. Other factors may relate to parasite loads; many parasites (such as hookworms) feed on blood and thereby remove iron from the body. Finally, there are genetic causes of iron deficiency, such as sickle cell anemia, which occurs where malarial infections run high and possessing some sickle-celled blood cells prevents one from becoming infected with malaria (one of the world's deadliest diseases).

In the skeletal system, cribra orbitalia and porotic hyperostosis are signs of iron deficiency. These features are found on the skull. Cribra orbitalia is visible on the inner eye sockets and porotic hyperostosis is visible on the rest of the skullcap. Both of these features are related to thinning of cranial bones and result in a hair-on-end appearance of bone when x-rayed. In growing individuals, the thinning is a result of hyperactivity of red blood cells that leads to the marrow spaces being filled with red blood cells and bone expansion without good bone cell formation. When examining the skull in a lab, these features look like pin-point holes in the skull, as if the bone had stopped growing and started healing, and like roughened bone that is very porous when the anemia was active at death (Figures 4.6 and 4.7). Since these traits occur during growth and development, they present an indicator of stress during childhood and not adulthood.



Figure 4.6. Example of healed cribra orbitalia from a prehistoric California hunter-gatherer population. Photo taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.

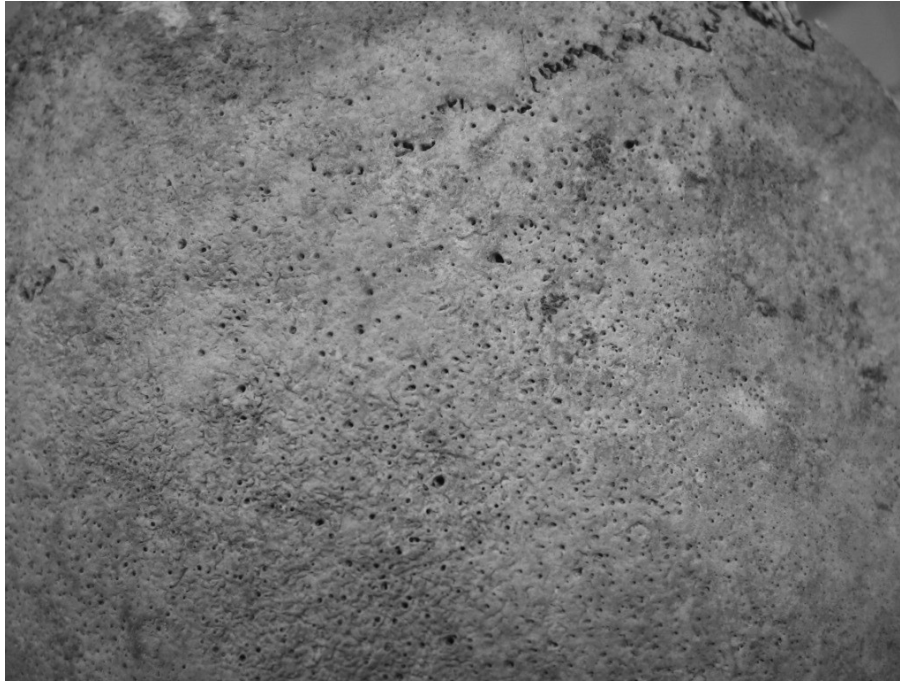


Figure 4.7. Example of healed porotic hyperostosis from a prehistoric California hunter-gatherer. Taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.

Research on skeletal samples from around the world has noted trends in cribra orbitalia and porotic hyperostosis; these articles often attribute the anemia to changes in diet, differences between classes, or parasite loads. Anthropologist Mario Šlaus (2008) worked on a large sample (nearly a thousand individuals) from Croatia dating from the Late Antiquity period (3rd to 5th Centuries) and the Early Medieval period (6th to 10th Centuries) to determine whether the trauma of the Christian invaders who ravaged urban centers, depopulated regions, and caused war and famine would be apparent in the health of the individuals as indicated by cribra orbitalia, enamel hypoplasia (a general health indicator mentioned above), bone infection, and trauma. Šlaus found that males of coastal populations had the most severe decrease in health with an increase in cribra orbitalia and other health stress indicators. Females seemed more buffered from the changes, which may be due to a biological sex difference as mentioned earlier. Even though the continental environment was harsher, it seems that the people on the coast either were more isolated from resources or did not exploit the marine resources as well as they perhaps could have. Another possibility is that they did consume marine resources to a greater extent, but that they ate their foods undercooked (possibly due to a desire to conserve resources) and, thus, had an increase in cribra orbitalia due to an increase in parasite loads.

A 2008 study by Marc Oxenham and Hirofumi Matsumura on cold-adapted peoples from Northeast Asia and Alaska used cribra orbitalia (and other health indicators) to look at health. Data was collected on over 200 individuals from several Japanese sites that date from 6000 to 1400 years ago, Alaskan sites (which included both Aleut and Eskimo populations), and compared them with previously published data from populations that occupied other North Asia and Southeast Asia locations. The authors found that Northern Japanese populations had

high frequencies of cribra orbitalia, which were higher than other cold-adapted people. They related the high frequency of cribra orbitalia with high parasite load (as we see in Southeast Asians) due to the undercooked and raw fish and marine animal foods that were consumed. Alaskan populations seemed to have a greater dietary variety and ate caribou and elk, which are less likely to be parasite-rich compared to marine resources, thus helping to explain their lower cribra orbitalia rates.

In Greek populations of the 5th to 3rd Centuries BC, anthropologists Keenleyside and Panayotova (2006) have also found evidence of anemia in skeletal samples. Greek samples are of interest due to the possibility that thalassemia (sickle-cell anemia) may be the cause of iron deficiency. The authors examined 184 individuals and determined that 28% had cribra orbitalia (subadults were more often affected than adults) and only 3.7% of the sample had porotic hyperostosis. Anthropologists in the past attributed high frequencies of cribra orbitalia in this region to sickle-cell anemia due to the fact that malaria was present in the area; however, iron deficiency caused by sickle-cell anemia displays thinning of facial and post-cranial (limb bones, sternum, etc.) bones. Sickle-shaped blood cells decrease the likelihood of catching malaria, which is a major health threat in areas with the malaria vector. The authors found that these early Greeks they examined had little evidence of thalassemia-induced anemia. Furthermore, isotopic evidence of diet suggests that the Greek diet was high in wheat and barley, which reduced iron absorption, and low in meats, which reduced iron intake. Interestingly, the authors also excluded other possible causes of anemic features, such as scurvy (vitamin C deficiency) by examining the sphenoid (an internal cranial bone) and the mandible (the jaw bone), since they are often affected by scurvy but not by iron deficiency.

In the New World, research over the years has linked anemia to a shift in subsistence patterns from hunter-gatherer to agriculture. For example in Southwest Pueblo populations, about a third of the skeletal samples in many populations have signs of cribra orbitalia or porotic hyperostosis (Larsen, 1997). And, in some samples, the rate is as high as three-fourths of the population being afflicted. The excessive rates of anemia seem to be related to an over-reliance on maize, which both reduces the intake of iron by decreasing the amount of meat consumption and by hindering iron absorption. Other locations, such as the Pacific coast foragers in British Columbia and all the way down to Santa Barbara had a very different diet, but high levels of anemia (from 13%-32% and on one island 72%). Their diets were rich in iron from marine resources, but parasite load may have been high due to contaminated waters related to high population densities or the consumption of undercooked foods (Larsen, 1997 and references within).

A final note about iron deficiency about sex differences in anemia is warranted. Females have often been said to be at greater risk for anemia due to menstruation, pregnancy, and lactation. However, the sex difference is not always found in skeletal samples and the sex differences would have to arise at puberty. Much of the cribra orbitalia and porotic hyperostosis is the result of iron deficiency in young years while individuals are still growing and skeletal indicators of adult iron deficiency are unknown as of yet.

4.4. DENTAL DISEASE

As seen above, anthropologists use a variety of skeletal and dental markers to determine health in past populations. The most common indicators of infectious diseases and dental health are: caries (which are commonly referred to as cavities), attrition (which is tooth wear; Figure 4.8), antemortem tool loss (which results in bone resorption and loss; Figure 4.9), calculus (or tartar), abscesses (which are locations of pus formation and drainage), and periodontal disease (also known as gum disease). In many prehistoric samples, within a single individual one can find evidence of caries, attrition, tooth loss, and bone resorption. Caries are the most often reported dental disease and the cause of caries is multifactorial, which means that there are many causes for caries formation. Caries can be defined as a disease process that is characterized by the demineralization of dental hard tissue, such as enamel, from the acid produced by bacteria that feed upon dietary carbohydrates, which turn to sugars (Watson, 2008). Caries rates have been shown to be one of the most effective ways to reconstruct the diet and health of past populations (Watson, 2008) and the use of caries in reconstructing the past has continued to provide useful information about populations (e.g., Arnold et al., 2007; Eshed et al., 2006; Keenleyside, 2008; Ubelaker and Pap, 2009; Watson, 2008; and many others). Caries alone, however, do not tell the whole story, and dental markers of health interact with each other; most recent studies use multiple methods to determine health. Some fairly universal trends that Larsen (1997) summarized include the increase in caries in the New World with the adoption of maize agriculture, a decrease in attrition being usually coupled with an increase in caries, and the fact that females tend to have more caries than males. Recent research on dental health has highlighted some important differences between New World and Old World agriculture and the effect on health, as well as looking at cultural variation that can lead to disease.



Figure 4.8. A prehistoric Californian with severe attrition. Photo taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.



Figure 4.9. A prehistoric elderly female with antemortem tooth loss and jaw bone resorption. Photo taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.

In the Old World, we see that the advent of agriculture and the adoption of agriculture have had a variety of effects on populations. Unlike in the New World, where the increase in caries with the adoption of agriculture is nearly universal, there are many cases where this does not hold true in the Old World. For example, Eshed and coworkers (2006) examined evidence of attrition, abscesses, caries, antemortem tooth loss, calculus, and periodontal disease in pre-agricultural populations and early agricultural populations of the Levant (which is also known as the fertile crescent and the location of the earliest evidence of agriculture) and found that attrition and periodontal disease was higher in the Natufian pre-agricultural population ($N = 1160$) compared to the Neolithic agricultural population ($N = 804$), but calculus (or tartar build-up) was higher in the agriculturalists. This difference in calculus may be a result of less wear on the teeth. Interestingly, Eshed and his colleagues noted no differences in caries. Another study in the Old World looked at Ukrainian samples from the 8th to 10th Centuries AD. Arnold and co-researchers looked at 33 individuals from agricultural and hunter-gatherer populations and found that the hunter-gatherers had lower attrition rates than the agriculturalists (which is the opposite of what is reported for most New World samples) and that there were no differences in caries rates. Ubelaker and Pap published a study in 2009 that looked at caries rates in Hungary within skeletal sample of 183 individuals for the Copper Age to the Bronze Age and Iron Age and found no significant increases in caries or tooth loss, even though caries rate increased slightly.

Not all of the Old World shows a lack of increase in caries rates with the adoption of agriculture; Temple and Larsen (2007) found evidence for increased caries frequencies in Japan. During the Yayoi period (2500 to 1300 years before present) of prehistoric Japan, rice agriculture was adopted and an increase in dental caries is accompanied by this switch when

compared to Jomon Japanese hunter-gatherers of the earlier period (4000 to 2300 years before present). They also found that females were more greatly affected by the rice consumption than were males; that is, they had a greater increase in caries rate than males. And, in Bulgaria, Keenleyside (2008) examined 5th to 2nd Century BC skeletal remains of 162 individuals. Caries rates were extremely high (52%), as were abscesses (20%) and antemortem tooth loss (16%). Dental problems increased with age and males had greater dental health problems than females, which the authors suggest may relate to males using their teeth as tools more frequently than females. Also, the high caries rate is associated here with a diet of soft foods and high carbohydrates. Interestingly, sex differences have been noted in diet in the Greek Colonies (such as this one in Bulgaria), but both isotopic analyses and caries rate show no evidence of sex differences in diet. Thus, although it appears that in the Old World some of the agricultural foods, such as millet and wheat, are not considered cariogenic (likely to produce caries) other agricultural foods, such as rice, may be as cariogenic as maize.

In the New World, there are some locations where agricultural did not impact the caries rate either. With a sample of 98, Watson (2008) examined caries and antemortem tooth loss at the La Playa site in northern Mexico. He found that non-agricultural Amerinds at the site had the same caries and tooth loss rates as the agriculturalists over a 1500-year time span (2000 B–500 AD). It appears that the hunter-gatherer diet of wild carbohydrates that included cacti, beans, and agave was as cariogenic as the maize consumed when agriculture was adopted.

Some dental disease is not related to diet, but rather culture. Use of teeth as tools led males of the Bulgarian Greek colony to have greater tooth loss and abscesses than females. In Pre-Columbian Chile, use of labrets (lip plugs) seems to increase periodontal disease in individuals as a result of abrasion (which is the wear of the biting surface from foods) on the teeth and gums (Torres-Rouff, 2003). Other causes of dental disease can be hide preparation as seen in arctic populations, such as the Aleut and Eskimo. Nonetheless, the vast majority of dental disease is likely related to diet and shifts in diet that either increase or decrease caries and attrition rates, which in turn can eventually lead to calculus build-up, periodontal disease, and tooth loss.

4.5. INFECTIOUS DISEASES: PARASITES, BACTERIA, AND VIRUSES

Specific Infectious Agents (Syphilis, Tuberculosis, and Leprosy)

Few infectious diseases leave distinct marks on bone, but anthropologists have begun to identify tuberculosis, syphilis, and leprosy in bone while excluding other possible causes of the bone lesions. These diseases are still present in today's world and, in fact, tuberculosis is the number one cause of death in the world. Due to impact of these diseases on modern populations, anthropologists are trying to find the origin of the diseases and understand the etiology and path of the diseases from local groups to worldwide pandemics.

Treponemal diseases are bacterial infections that are caused by various species and sub-species of the genus *Treponema* (Table 4.1). Symptoms include deformation of legs and feet, and destruction of the nasal and palatine bones. Also, syphilis diseases can attack the central nervous system and cause insanity. Treponemal diseases can be divided into four groups:

pinta, yaws, endemic syphilis, and venereal syphilis. Pinta does not leave any lesions on bone and, thus, is not considered in paleopathological studies. The other three forms of treponema leave the same lesions on bone and, as a result, they are difficult to tell apart. Furthermore, they are so similar that even DNA studies cannot always distinguish them. Endemic syphilis and yaws are spread via skin or mucous contact, whereas venereal syphilis is spread through sexual contact. In locations where non-venereal treponema is active, venereal syphilis seems to be absent and vice-versa. Congenital syphilis, which is obtained through the mother in-utero, is only common in venereal syphilis infections and results in abnormalities of the teeth (Hutchinson's incisors and Mulberry molars; Figure 4.10). In skeletal remains, anthropologists look for evidence of treponema through looking at pitting and scarring of the skull (Figure 4.11), destruction of the nose and hard palate, tibia that look like sabers, and inflammation of the forearms. Destruction of the nose and palate is most common in yaws, whereas destruction of the elbow, hip, knee, and skull are most common in venereal syphilis. As mentioned above, teeth abnormalities are usually a sign of a venereal infection of the mother of the offspring.

Table 4.1. List of variations of syphilis diseases, the causes of the disease, and their skeletal markers

Disease	Variations	Cause	Skeletal Markers
Treponemal (Syphilis)	Pinta	Bacterial/through skin and mucus	None
	Yaws	Bacterial/through skin and mucus	Destruction of the nose and palate.
	Endemic syphilis	Bacterial/through skin and mucus	Destruction of the nose and palate.
	Venereal syphilis	Bacterial/passed through sexual contact	Destruction of the elbow, hip, knee, and skull bones.
	Congenital	Bacterial/passed from mother to infant	Abnormalities of the teeth



Figure 4.10. Dental abnormalities as a result of congenital syphilis. From http://phil.cdc.gov/phil_images/20021114/34/PHIL_2385_lores.jpg. Creation Date 1971. Author CDC/Susan Lindsley.



Figure 4.11. Cranial vault scars as a result of syphilis. From Acoma.

Causes of any infectious disease outbreaks seem to be linked to increase in population growth, crowded environments, lack of sanitation, and other stresses (such as warfare). In the Tennessee River Valley, anthropologist Smith (2006) found evidence of treponemal disease prior to the adoption of agriculture. Smith found that, in the Late Archaic period (starting around 6000 years ago), which is defined as a hunter-gatherer pre-ceramic period, treponemal infections are found mainly on subadult skeletons. In the later Early Woodland period (ending around 1 BC), which marks the onset of pottery and ceramics that led to increased sedentary behavior and therefore the possibility of increasing population growth and more crowded conditions, treponemal infections were higher in frequency (i.e., more people were infected). However, the remains of the infected individuals were adults suggesting that in the later period more individuals survived their infections and there may have been more recuperative care possible in the sedentary culture of the Early Woodland period, as opposed to the Late Archaic period.

Anthropologists examining treponemal evidence have debated the origin of syphilis for decades. Anthropologists are in disagreement whether syphilis was in the Old World prior to Columbus's return from the New World. Three possible theories of syphilis origins have been put forth: 1) Syphilis was in the Old World prior to Columbus's return, but it was mild and not widespread. Doctors may have misdiagnosed the disease and there may have been a mutation that resulted in syphilis changing from the endemic version to the venereal version; 2) Syphilis was introduced to the Old World through Columbus's return. Studies of thousands of Old World skeletons have revealed no pre-1493 cases of syphilis in Europe while in the 1500s we suddenly have cases of syphilis appearing. The oldest case of syphilis is around 6000 years from South America; 3) Multiple origins are possible, and *Treponema* was present in both the New and Old World, perhaps even originating from primates millions of years ago, but the environment dictates whether venereal or endemic syphilis will thrive (e.g., Buzhilo, 1999; Erdal, 2006; Hutchinson and Richman, 2006; Larsen 1997; Smith, 2006).

Recent evidence may help determine the origin of syphilis, but anthropologists are cautious in their diagnoses, since many infections leave similar lesions on bone and some cases are not as conclusive as one might desire (Hutchinson and Richman, 2006). Anthropologists are coming to accept that there is a possibility that syphilis was in the Old World prior to Columbus's return, but whether venereal syphilis was present prior to his return is still very controversial. In the New World, Hutchinson and Richman (2006) examined treponemal infections in the Southeastern United States and found that there was no evidence of venereal or congenital syphilis, but endemic syphilis was found in 25 sites dating from 8000 BC to 1600 AD. This article points out that New World syphilis has been around for a very long time, but that evidence of venereal syphilis is found only in the Old World that could mean that syphilis mutated in the colder climes of Europe to be spread more effectively in locations where the presence of clothing would minimize the transmission of syphilis through contact. Interestingly, the authors also point to the increasing frequency of syphilis over time, which may relate to the increasing population sizes and increase in sedentary behavior.

Old World evidence of syphilis prior to the return of Columbus has been found by Erdal (2006) in a Turkish skeletal individual in 13th Century AD. Erdal points out that evidence of syphilis in the Old World prior to 1493 is very scarce and he tries to determine whether venereal syphilis is present in this pre-Columbian Anatolia case by examining dental evidence to more securely diagnose venereal syphilis presence. Erdal found that a teenager of

approximately 15 years of age in this Turkish site had post-cranial lesions and destruction of the maxillary bone (upper jaw and nasal region) similar to syphilis cases; furthermore, Hutchinson incisors and abnormal molars are also documented. Erdal suggests this is a clear case of venereal syphilis in the Old World that pre-dates Columbus's return. However, there may be other possible diagnoses and one needs more than a few rare case studies of poorly preserved remains to turn over a theory.

Tuberculosis is the leading cause of death today and is a world-wide threat due to antibiotic-resistant strains that are a direct result of antibiotic use in feeds to livestock, overuse of antibiotics (such as using antibiotics for cold virus treatment), and misuse of antibiotics (such as not finishing up antibiotic regimens when ill). Tuberculosis is a bacteria that destroys bone and yet also results in new bone formation. Most common locations of lesions are in the ribs and vertebral column; in part, the locations of bone reactions are due to tuberculosis residing in the lungs and the proximity of the lungs to the ribs. Tuberculosis is spread through the air by individuals with active infections whose symptoms include coughs. Other symptoms are bloody coughs, weight loss, fatigue, night sweats, painful breathing, lung damage, joint destruction, and vertebral collapse. Tuberculosis has been dated back to 5000 years in an Egyptian mummy (Larsen, 1997). The infectious disease seems to increase when population growth occurs. Diagnosis in the clinical setting is straightforward, but in the paleopathological record many other diseases (such as pneumonia, brucella, or fungal infections) leave similar marks on bones (Matos and Santos, 2006). Some of the most effective ways of diagnosing tuberculosis in the skeletal system include examining ribs 3 through 7 for bilateral bone remodeling and lesions. Right sides are more frequently affected than left sides.

Like syphilis, the origins of tuberculosis are a hot topic in paleopathology. Theories include that tuberculosis has an Old World origin and was brought over to the New World by Columbus or that, in the Old World, European contact was not the cause of tuberculosis (TB) in Asian or African populations, and that perhaps there are multiple origins of tuberculosis (e.g., Lambert, 2002; Spigelman et al., 2002; Suzuki and Inoue, 2007). Lambert (2002) examined rib lesions in the remains of 32 individuals from Colorado and found that about a third of these pre-contact (1075–1280 AD) Ute Indians had rib lesions that may have been induced by tuberculosis. More females and young individuals were afflicted, a pattern also found in the clinical literature. In addition, these Colorado Indians were occupying a marginal area, where competition for resources led to warfare and likely caused increased stress and susceptibility to tuberculosis (which is also documented in clinical studies). Other cases of tuberculosis in pre-contact Indians have been found in Arizona and New Mexico. Nevertheless, one must be cautious since these cases could also be related to other respiratory ailments.

Suzuki and Inoue (2007) documented cases of possible tuberculosis through collapsed vertebrae in the Yayoi of Japan who practiced agriculture and were sedentary. The Yayoi period (300 BC–300 AD) is marked by an increase in warfare, social stratification, and polity, all of which can lead to increased infectious disease rates. Furthermore, it appears that immigrants were abundant in this area and may have brought the disease with them (although Europeans had not made contact). Other pre-European contact evidence for tuberculosis in Asia and the New World comes from ancient DNA (aDNA) studies of Bornean skeletal remains and South American (Chilean and Peruvian) mummies. It appears that in aDNA studies the similarity of tuberculosis with bovis infections are highlighted, which suggests

that tuberculosis probably has a zoonotic origin and may have arisen in any place where animals and humans were in close contact (Zink et al., 2007).

Unlike tuberculosis and syphilis, most people have a natural immunity to leprosy. Nonetheless, there are geographic pockets (tropics and subtropics of Africa, Asia, and South America) where leprosy thrives and immunity seems absent. Often, leprosy and tuberculosis co-exist and can be confused in the skeletal record. Like tuberculosis, leprosy is also caused by a bacterium and is transmitted by inhalation or contact with an open wound, but it is much more difficult to become infected with leprosy than tuberculosis. The incubation period of leprosy can be decades long and is rarely fatal, but it does cause disfigurement. Symptoms include loss of peripheral nerve sensation and poor blood circulation; minor cuts can lead to loss of fingers and toes since no healing occurs when the body is injured (Figure 4.12). Currently, males are more often affected by leprosy, but the symptoms are more severe in women. Anthropologists look for evidence of facial and nasal bone destruction, loss of distal elements (toes, fingers, etc.) and no signs of healing to diagnose leprosy.

The earliest cases of leprosy occur in Israel (1411–1314 BC), India (600 BC), Scotland (1600–2000 BC), and Egypt (200 BC) (Larsen, 1997). Leprosy peaked in its frequency and severity in Europe from 1400 to 1500 AD and disappeared by 1900s, but there were a few surges in Iceland and Norway (Larsen, 1997). By 1000 AD it seemed to have reached central Asia, perhaps as a result of trade with Israel. New World evidence of leprosy prior to European contact is absent, which provides good evidence that the origin of leprosy is in the Old World (possibly Africa or Asia). Blau and Yagodin (2005) found evidence of nasal cavity resorption in West Central Asia that dates back to the 3rd and 4th Centuries AD, which the authors link to the migration implications mentioned above. Walker (2008) examined a possible case of leprosy in a young adult male in 19th Century England; by this time, most Europeans were not being infected by leprosy but this young male may have been to India or another British colony (as suggested by his elite status and treatment). Although his treatment included amputation, he died not of leprosy but another infection. Sometimes, infected individuals have lowered immune systems and are more likely to get tuberculosis or other bacterial infections that lead to death. Interestingly, when tuberculosis takes hold in Europe, leprosy seems to decrease; there may be some inter-species competition that occurred. Although leprosy, tuberculosis, and syphilis can usually be diagnosed, many infectious agents are not easily identified.



Figure 4.12. Loss of toes as a result of leprosy. Photo taken by Cnyborg at the museum Ribes Vikinger, Ribe, Denmark, May 2005.

General Infectious Agents

Normally, bones are protected by soft tissue, but infectious agents can enter the system either through a fracture (such as when one is injured) or through the circulatory or lymphatic system, which includes bacteria and viruses that are inhaled (such as in the pneumonia or tuberculosis) or consumed (such as in *Salmonella*). Infections that are common in modern day peoples and, therefore, likely prehistoric populations, include *Staphylococcus* infections, *E. coli*, *Salmonella*, and *Gonorrhea*. Many infectious agents leave the same marks on bones and, for the most part, anthropologists cannot necessarily determine the agent of infection. Nevertheless, the frequency and trends of infections can aid in reconstructing past populations' health, especially in regards to changes in culture, temporal trends, and subsistence pattern shifts (Larsen, 1997). Another difficulty to mention is that few infections actually leave traces on bones and chronic infections may actually be a sign of good health, since a weak individual may die faster than a healthier individual; thus, the skeletal signs of infection are actually the result of an individual surviving longer than those that may die with perfectly healthy-looking skeletons. Furthermore, there are questions regarding the legitimacy of regarding all periosteal reactions (these are reactions that take place on the periosteum, see chapter 2, and do not affect the medullary canal) as being indicators of infection, which will be addressed again later (Weston, 2008).



Figure 4.13. Femur (Front) and tibia (Back) with osteitis. Photo taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.

Skeletal lesions from infections are common pathologies, but they are not often recorded in the bioarchaeological literature. To complicate the matter further, the recording of the infectious lesions are not standardized (i.e., anthropologists use a variety of recording procedures) and due to this it is difficult to compare across studies. In general, skeletal lesions from infections (also known as osteitis) are recorded as being on a continuum from least severe to most severe (Figure 4.13). The least severe form is periostitis (also known as a periosteal reaction). Periostitis by definition is when an infection causes the elevation of the outer layer of the periosteum, which is due to compression and stretching of blood vessels as a result of an agent such as pus or blood build up (Weston, 2008). Periostitis is usually localized to one or two bones that are infected and it is rarely fatal. The more severe infection is that of osteomyelitis, which is often fatal and involves the medullary cavity. With osteomyelitis, many bones are involved and the infection spreads through the medullary cavity. The appearance of osteitis and osteomyelitis involve more severe elevations than periostitis and often cloacae, which are pus-draining holes. Pus is the result of white blood cells trying to fight off the infection.

Larsen (1997) highlighted some trends of infections that include increases in periostitis and osteomyelitis with the advent of agriculture and with population growth. Recent research has highlighted some variations in infection rates that support earlier work summarized by Larsen (1997). For example, Oxenham and colleagues (2005) examined infection rates of North Vietnamese populations from the Bronze and Iron Age (3300 to 1700 years ago) compared to the earlier sedentary coast foragers (6000 to 5500 years ago). They found that in the early population no infections could be recorded, but in the Metal Age populations about ten percent of the sample had infectious lesions. The authors attributed this rise in infections to the onset of chiefdoms that was coupled with agriculture, warfare, and large population growths. Another interesting study examined infectious disease in skeletal populations from later medieval Serbia (Djurić-Srejić and Roberts, 2001). They found that, in a sample size of 1617 skeletons from eight medieval Serbian cemeteries, infection rates were high and written

records support this high rate of infection. Nearly all infections were non-specific and some may have been related to injury. Interestingly, all the chronic infections in the sample were found in adults, which either suggests a protection for young individuals from infections or more likely that infections were more likely to kill young individuals prior to leaving a mark on the bone. About 30% of infections led to death in Serbia prior to the use of antibiotics and, thus, this lack of evidence of infections on young individuals is most probably a sign of early death from infections rather than healthy lives.

In another study from Europe, Capasso (2007) provides evidence of natural antibiotic use in southern Italy in the 1st Century AD. Herculaneum was a Roman town hit by a tremendous volcano that resulted in a skeletal collection of excellent preservation and a unique record of early Italy. Capasso examined a sample of 162 individuals who were nearly perfectly preserved (since they died by being buried in falling volcanic ash) and had remains of their foods as well, which consisted of olive oil, bean soup, almonds, walnuts, wine, dried figs, and dried pomegranates (among other things). Examination of these foods with a stereomicroscope and a scanning electron microscope revealed that the pomegranates and the figs had a fungal growth that had antibiotic qualities. Written records of pre-Roman and Roman physicians suggest the use of figs and pomegranates to cure all sorts of health ailments. The examination of the skeletal remains (both by sight and histologically) provided evidence of lice, which led to non-severe cases of periostitis, but few other cases of infection. Non-specific inflammatory bone changes were rare in this population. The histological study of the remains provided evidence that the bones had properties of tetracycline in them that most likely came from fig and pomegranate consumption and protected this population from more severe cases of infection, such as osteomyelitis.

Although anthropologists use evidence of bony changes as signs of infection, some anthropologists have questioned the use of periostitis as an indicator of infection. Anthropologist Darlene Weston (2008) examined periosteal reactions of museum specimens and found that reactions were often the result of trauma and bone remodeling without inflammation or infection. She questions the use and definition of periosteal reaction as an indicator of infection due to her findings. Additionally, Djuric and colleagues (2008) examined signs of lesions of 327 immature individuals from Serbia and found that infections that result from parasites can result in anemia and, thus, can be misdiagnosed as dietary deficiency rather than an infectious agent cause. Finally, as Djurić-Srejić and Roberts' (2001) report indicates the lack of skeletal indicators of infections may actually be due to the likelihood that individuals who have weaker immune systems die prior to the infection leaving marks on the bone and, thus, we are reversing the signs of health (i.e., it is a healthier individual with chronic infections that they survived and fought off, rather than an individual who dies soon after contracting the infection).

4.6. Congenital Diseases and other Miscellaneous Pathologies

Most anthropological studies on congenital diseases, which are diseases that are contracted through birth and can be due to the prenatal environment or genetics, are either case studies of a single individual or a very small sample or an examination of a specific disease in a population. In part this is due to the data; severe congenital pathologies are only

rarely found in bioarchaeological skeletal collections, which is likely due to the early death of individuals with severe pathologies and the fragility of infant and child bones that makes their remains rare, regardless of their health (e.g., Bello et al., 2006; Guy et al., 1997; Weiss, 2008a). However, there is another confound: clinical diagnoses may differ from skeletal diagnoses.

Pathologies that we think of as problematic in the bioarchaeological record, such as spina bifida occulta, may go undiagnosed in modern peoples (Figure 4.14). Spina bifida is a lack of vertebral spine fusion that leaves the spinal nerves vulnerable and can lead to retardation, immobility, and fetal death, but it can also be less severe and only affect the sacrum (the bottom of the spine) and cause no health issues. Nevertheless, studies of spinal defects are among the most common congenital pathologies reported. Severe abnormalities, such as spina bifida cystica (which is complete lack of vertebral fusion), are usually lethal in the early stages of life. Thus, the study of these abnormalities remains limited in skeletal populations. Yet, less-severe forms of pathologies can be studied and compared to past and present populations' frequencies to understand causes, changes through time, and past cultures. In regards to spina bifida, anthropologists have studied 11th Century Slovenia, 3000 year BP Egyptian populations, 10000 year BP Moroccan samples, and prehistoric and proto-historic Amerind and Arctic populations (Bennett, 1972; El-Din and El Banna, 2006; Ferembach, 1963; Masnicová and Beňuš, 2003; Merbs, 2004; Weiss, 2007a). Rates of spina bifida ranged from 24% in the Moroccan sample to 3% in the Egyptian sample.



Figure 4.14. A California Amerind adult male with spina bifida occulta. Photo taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.

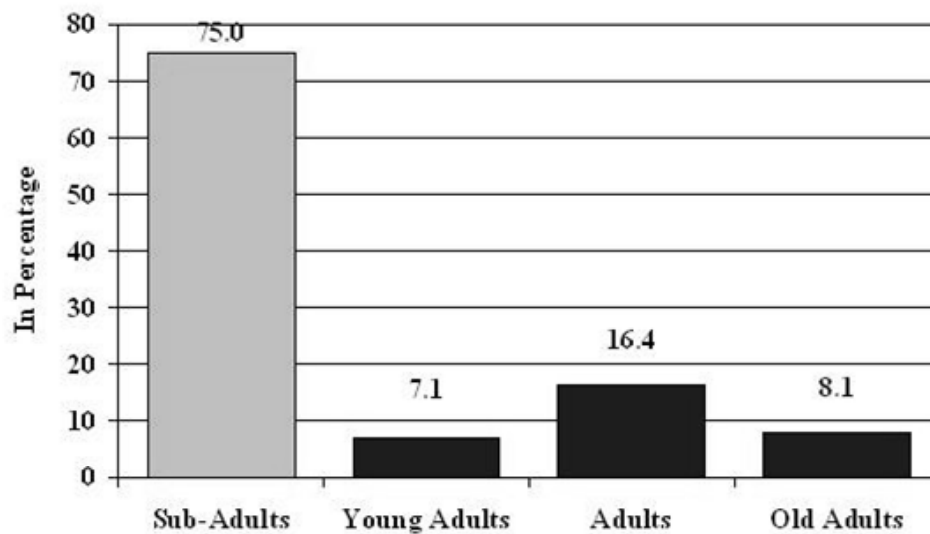


Figure 4.15. Age differences in individuals diagnosed with spina bifida occulta; note that the youngest age group presents the most cases of spina bifida implying that increased mortality or decreased longevity may be associated with spina bifida occulta. Modified from Weiss (2008a).

Diet influences spina bifida frequencies. In the California Amerind sample, acorns were the staple food of prehistoric Californians and, thus, their diet resembles agriculturalists with an emphasis on a single starch (i.e., acorns rather than maize) and the rate of spina bifida in the Californian sample was 16.5%. Ancient Egyptians, conversely, ate large quantities of lentils, a high-folate food, and had the lowest frequency of spina bifida (El-Din and El Banna, 2006). In modern populations, before folate fortification, sacral spina bifida rates were between 14 to 24%. Some of the variance is due to genetic, while other variance is dietary (Weiss, 2007b). New research has found a recent increase in spina bifida linked to poor diets. Inbreeding has also been linked to increased spina bifida (Bennett, 1972; Weiss, 2007b). In modern populations, spina bifida occulta is not often diagnosed and we have no accurate idea of its frequency, although the percentage is given at around 15-20% in modern populations based on a few studies (see Jorde et al., 1983). Additionally, scientists are not sure of the connection between spina bifida occulta and more severe cases of spina bifida (Hall and Solehdin, 1998; Jorde et al., 1983). On the other hand, in skeletal populations individuals with spina bifida cystica would have died shortly after birth and the remains are likely not to survive the thousands of years of diagenesis (Ferembach, 1963). Furthermore, Weiss (2008a) has noted a decrease in longevity with individuals who were afflicted with spina bifida occulta in the California Amerind hunter-gather sample (Figure 4.15). For skeletal populations, it would follow, the consideration and documentation of minor pathologies is essential.

Whereas anthropologists looking at vertebral pathologies look at population patterns to draw conclusions about diet and inbreeding, other anthropologists publish on single individuals with pathologies in case studies (e.g., Anderson, 2003; Formicola and Buzhilova, 2004; Malgosa et al., 1996; Molto, 2000). Case and coworkers (2006), for example, looked at polydactyl (which is having extra fingers and toes and has been linked to inbreeding) in two

Prehistoric American Southwest individuals. Mann and colleagues (1998) studied an adult female from Moundville, Alabama dating from 1200 to 1400 AD with a fused humerus and radius and a missing ulna. The authors also examined the rest of the skeleton, but due to the fragmentary condition of the bones they did not find additional pathologies. Phillips and Sivilich (2006) provide a case study of a prehistoric Native American from Indiana dated to 500 to 1000 AD with a cleft palate. This Indiana individual was a young adult female who had several pathological lesions that suggest a cleft hard palate and an affected nasal region. Furthermore, the individual appears to have infected sinuses and dental caries. The authors mention the difficulty in comparing this individual with modern individuals since they are likely to receive medical attention prior to adulthood; the disparity in lifestyle due to medical progress makes reconstructing the prehistoric individual's quality of life difficult. Dickel and Doran (1989) examined an individual from Florida with a severe neural tube defect. This Florida female lived about 7500 years BP and died at the age of about 15 years old; she had spina bifida aperta (running through her thoracic vertebrae and likely causing immobility). Secondary pathologies were also found, such as enlarged nutrient foramen (sometimes associated with Gaucher disease that causes renal and blood disorders), disuse atrophy of the limbs, vertebral curvature, and cone-shaped epiphyses of the hand phalanges (fingers). It is quite remarkable this female survived until her teen years; she was likely cared for by her community. Another study found 30000-year-old Slovakian burials of well-preserved skeletal remains that had deformities of femur, fibula, radius, and ulna, along with scoliosis and misshapen vertebral spines (Masnicová and Beňus, 2003). The authors suggest that these anomalies can be linked to various possible syndromes, such as chondrodysplasia calcification punctata (an inherited bone disorder).

Weiss (2008a) tried to combine the studies of multiple pathologies with those of larger sample sizes. She looked at a pre-European California sample of 284 individuals. The California hunter-gatherer population had a high rate of congenital pathologies possibly due to inbreeding. Supernumerary teeth and spina bifida occulta both have been linked to inbreeding (e.g., Bennett, 1972; Lovett and Gatrell, 1988; Mahaney et al., 1990) and were frequent in the California sample. Inbreeding may have been due to the elite status of these individuals. Weiss's results support that individuals born with a congenital pathology often have other congenital pathologies, which is what we find in the current medical literature. Individuals who had cleft palates also were afflicted with numerous other pathologies. One Californian individual had fused cervical vertebrae (Figure 4.16), sacralization, and a sagittal vertebral cleft; this person may have had Klippel-Feil syndrome, which is also associated with renal (kidney), cardiovascular (heart), and otology (ear) abnormalities. Another adult had an abnormally small external auditory meatus (or ear canal), which can be a characteristic of deafness, sacralization, and spina bifida occulta. Anthropologists should try to link multiple pathologies in single individuals to modern syndromes to better understand the past individual's health, but they must also be cautious to avoid over diagnosis when the skeletal remains are not indicative enough of any particular ailment. Case studies should not be abandoned in this field, especially when the probability of finding numerous individuals with specific pathologies is low and less severe pathologies of the population should not be ignored (Weiss, 2008a).



Figure 4.16. An adult male with fused cervical vertebrae (which is a trait of Klippel-Feil syndrome). Photo taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.

Cancer

Many students of bioarchaeology may wonder about other diseases found in modern populations that are not discussed at great lengths in the field of bioarchaeology. Were modern diseases, such as cancer, hypertension, heart disease, high cholesterol, and hardened arteries, present in past populations? If they were not present, then are these diseases due to modern environments, such as low activity levels, high fat and caloric intake, or pollution and smoking? Or are the diseases found in modern populations a result of longevity that did not exist in prehistoric times? The answers to these questions sometimes elude bioarchaeologists; in part, some diseases are not present because they do not affect the skeletal system. For example, as mentioned previously, hardened arteries have been identified in Egyptian mummies of old ages through macroscopic examinations during autopsies (Ruffer, 1911). Mummies provide useful information for diseases that do not leave marks on the skeleton since soft tissue is preserved in many skeletal remains.

One exception to the modern diseases and lack of data in the skeletal record can be seen in the tumor or cancer literature. Osteosarcomas can be divided into primary malignant bone tumors and their appearance is usually very distinct and difficult to miss, such as “flower bursts” on skulls and secondary bone tumors, which may be less visible but account for the bulk of bone cancers today (Waldron, 1996). These secondary tumors occur when non-bone cancers metastasize to the bone tissue. Although many anthropologists argue that there are large differences in cancer rates between modern and past population, others have argued that cancer rates in prehistory are difficult, if not impossible, to calculate for past populations (Waldron, 1996). It appears that cancer rates are not only difficult to calculate due to the rarity of certain cancers, but also because cancer does not always metastasize (spread) to

bone. To further complicate findings, tumors in skeletal individuals are often fragile and may be broken prior to reaching laboratories for examination (Waldron, 1996). With this said, there are cases of cancer that have been documented in late Holocene Argentina, medieval Germany, Denmark, and England; these cases have used diagnostics that include macroscopic investigation, radiographs, scanning electron microscopes, and histological examinations (Alt et al., 2002; Anderson et al. 1992; Grupe, 1988; Luna et al., 2008; Melikin, 2006; Tkocz and Bierring, 1984). These published articles are usually in the form of case studies that intend to provide evidence of cancer along with other possible diagnoses (sometimes the other diagnosis is more apt to be correct; e.g., Perry et al., 2008). Their descriptive nature is reminiscent of earlier bioarchaeological works, but due to the rarity of these finds these methods are the only ones available to the anthropologists. Some of the descriptive studies may also help anthropologists identify cancers in new finds, such as noting that cancer can appear as lytic lesions that look like holes in the bones while other cancers are present as excessive bone growth (Alt et al., 2002; Melikian, 2006; Waldron, 1996). Figure 4.17 illustrates excessive bone growth due to cancer in a clinical case. Additionally, diagnoses include consideration of age, sex, and which bones are affected (e.g., Melikian, 2006; Tkocz and Bierring, 1984).

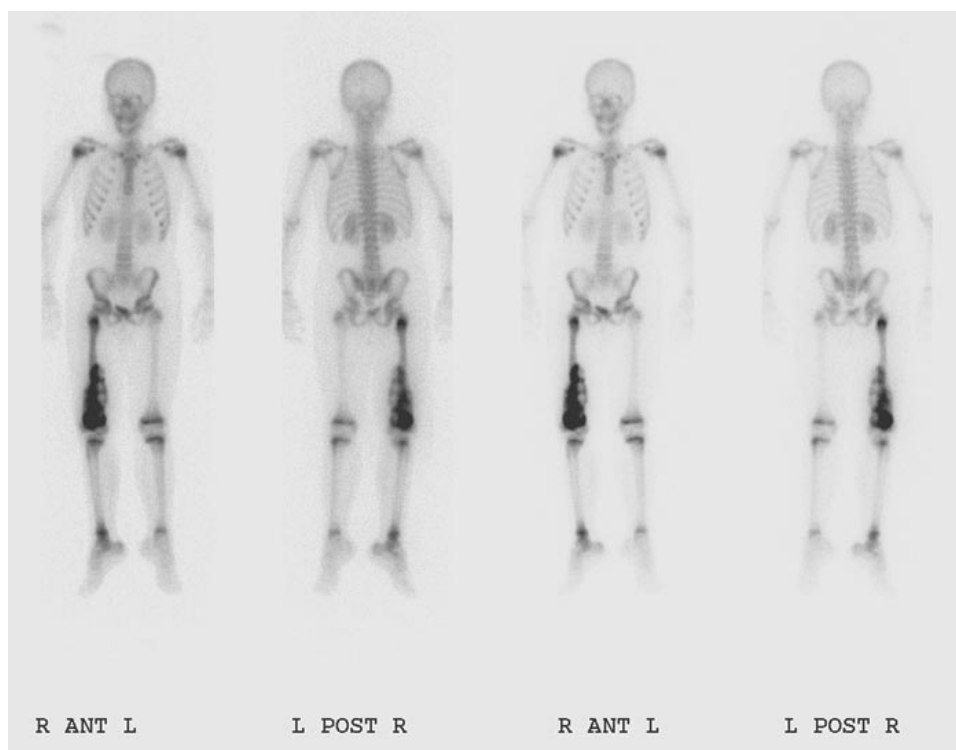


Figure 4.17. A case of osteosarcoma of right femoral bone - scintigraphy of the whole body. Date 8 January 2008RadsWiki.

Some interesting cases from the bioarchaeological record, for example, include the examination of an elderly man from medieval Canterbury England with prostate cancer as diagnosed by scanning electron microscope use as well as the above diagnostics considered (Anderson et al., 1992). This medieval British male skeleton was between 45 and 55 years of age and appeared to have diffuse idiopathic skeletal hyperostosis (which is characterized by excessive calcification along the sides of the vertebrae of the spine). Additionally, scanning electron microscope images showed that the excessive bone thickness in his mandibles, pelvis, and ribs appear similar to clinical cases of cancer with disorganized labyrinth of bone appearing and causing bones to be heavier and denser. Due the male's age and the distribution of the excessive bone formation, the authors suppose that this is evidence of prostate cancer in medieval Europe.

Another interesting case involves a child with osteosarcoma diagnosed from the right femur through macroscopic investigation, x-rays, and histology (Alt et al., 2002). It appears that the child of 8 to 10 years of age (who was likely a male) had cancer that took the form of excessive bone growth as a large tumor on the femur's proximal end; the microscopic view shows new bone formation in a vertical pattern that is also found in clinical studies of osteosarcoma. Interestingly, this individual also had cribra orbitalia that may have been in part to the ill health of the child who would have been in severe pain and likely immobile. The cause of the cancer, Alt and colleagues suggest, was the vicinity to lead-silver mines that may have infected the child.

And, the final case of interest that will be reviewed comes from a female skeleton from 18th Century London (Melikian, 2006). Ann Sumpter died at the age of 31 in 1794, her skeletal remains are filled with lytic lesions that appear on the skull, vertebrae, and ribs. Some of the lesions are complete through the bone while others can only be seen in radiographs. Her diagnosis by Melikian was metastasized breast cancer; although she was a bit young for cancer, the clinical literature reports that individuals who have breast cancer at young ages often have more aggressive and more fatal forms of the disease.

Waldron calculated that in past populations the rate of these cancers should be around 30 per 100,000, which makes finding any cases difficult and the reporting of these cases important. Thus, it appears that cancer was present in medieval times and even earlier, but there may have been severe differences in frequencies.

4.7. Chapter Summary

Bioarchaeologists are handicapped when diagnosing diseases; they only have the skeletal system to examine and many diseases leave similar marks on bones. Furthermore, signs of stress, such as Harris Lines, are now being thought of as possible indicators of health since the individuals bearing these marks actually survived through the hard times and resumed their lives and growth. Even with these difficulties, anthropologists studying the skeleton have come to be able to diagnosis some specific ailments, such as syphilis and tuberculosis, due to examination of the clinical literature and sometimes even DNA studies of the microbes. We have also learned that some of the biggest threats to human health in the past are still threats to health today, such as tuberculosis, whereas other diseases appear rarely in today's populations that were much more prevalent in past populations, such as rickets.

Nevertheless, some diseases are making comebacks and bioarchaeology provides some useful lessons on health and diet, such as the occurrence of spina bifida and consumption of naturally folate rich foods, which is a reminder to consume healthy foods rather than depend on fortified foods that may go in and out of fashion. Finally, it is important to note that the weakest or sickest individuals may have died without any skeletal markers of disease or stress since usually the skeleton is not the part of anatomy to be afflicted; when people died who seemed otherwise healthy, the assumption could be made that they did not survive long enough for the disease to affect their bones.

Key Terms

Anemia
Attrition
Caries
Congenital birth defects
Colles' Fracture
Cribra orbitalia
Enamel hypoplasia
Harris lines
Leprosy
Osteomalacia
Osteomyelitis
Osteosarcoma
Periostitis
Porotic hyperostosis
Rickets
Spina bifida
Stature
Tuberculosis
Treponema

Chapter Questions

- 1) What are some of the difficulties bioarchaeologists face when diagnosing illnesses?
- 2) How can some signs of stress be viewed as positive and negative health indicators?
- 3) What are the theories of origin for syphilis and tuberculosis?
- 4) What causes leprosy and what are signs of leprosy in the skeletal record?
- 5) What are syndromes and how are they diagnosed in the skeletal record?
- 6) How does folate consumption influence spina bifida rates?
- 7) What evidence for modern diseases of cancer, arteriosclerosis, and heart disease do bioarchaeologists find in skeletal remains?

Chapter 5

TRAUMA: ACCIDENTS, VIOLENCE, AND SURGERY

5.1. INTRODUCTION TO TRAUMA ANALYSES

Trauma or injury patterns are used by anthropologists to assess cultural variation in behavior, the impact of subsistence patterns on activities, interpersonal aggression levels, and the impact of environmental terrains. Most injuries certainly are not identified on skeletal remains since the bone has to be affected for anthropologists to be able to see an injury. Also, most cases of injury, whether they are accidental or intentional, seem to be reported as case studies or population specific in the literature. For example, Upex and Knüsel (2009) reported on a singular 20-something year-old male who lived in 10th Century Britain with a separation of his first thoracic transverse processes. The authors attribute the fractures to overloading, such as in pulling or dragging items, or in extreme rotation of the back as we see in people who shovel for a living.

Nancy Lovell (1997) has outlined the problems anthropologists may come across when identifying traumatic lesions on bone. Problems of identifying causes of injury can relate to multiple causes leaving the same fracture types on bones; these types of problem may result in over emphasis on the more exciting probable causes, such as warfare, as opposed to emphasizing the probability of accidental causes, such as falls. In order for anthropologists to diagnose a traumatic lesion, they first must determine whether the injury was antemortem (occurred prior to death), perimortem (occurred around the time of death), or post-mortem (occurred after death). Many mistakes in reconstructing past civilizations have been published due to the lack of knowledge about fractures that occur prior to death compared to those fractures that occur after death. In general, antemortem fractures are clearly recognizable since they show evidence of healing; the greater problem with antemortem fractures is that they may be missed if the fracture happened a long time prior to death and bone remodeling has erased the evidence of the fracture.



Figure 5.1. An example of pseudoarthrosis from prehistoric California. Photo taken by Robert Jurmain, scanned by San Jose State University's Instructional Resource Center.

The repair process in antemortem fractures varies due to individual health, age, and the complexity of the fracture. Nonetheless, usually there are three steps in the repair process. First, blood supply is disrupted and causes death of bone adjacent to the fracture, which results in blood coagulating around the surrounding tissues. Next, a fracture callus forms around the injury site that bridges the separated parts and supports the bone until permanent bone is replaced. This callus formation starts around 2 weeks after the fracture occurred and is resorbed usually after around a month. Third, the callus is converted to permanent bone through bone remodeling. Sometimes fracture sites are never completely healed or never revert back to the original form, whereas other times it may require an x-ray to see if a fracture occurred. On the other hand, fractures may not align properly or muscles may pull the bone in different directions that lead to disfiguration of the limb. One example of this disfiguration is pseudoarthrosis, which occurs when there is a non-union (or a lack of fusion) of a complete break (Figure 5.1).

Perimortem and post-mortem fractures do not undergo the repair process. Perimortem fractures occur when the bone is still moist and elastic (which we also sometimes call green). Long bone perimortem fractures tend to have sharp edges and are often longitudinal or spiral. Furthermore, small flakes of bone are sometimes held in place by periosteal tissue. It is important to realize that bone can stay “green” for several years after death in certain depositional environments and depending on the age of the individual; therefore, it is essential to take into account the mortuary context of the remains. Post-mortem trauma usually occurs when the bone is brittle and dry; fractures appear as irregular lines and there are no adhering bone flakes. Long bone post-mortem fractures can also be transverse and splintered. On the crania, we usually see depressions in antemortem and perimortem fractures or injuries, but shattering the bone in post-mortem cases.



Figure 5.2. An example of a projectile point embedded in a lumbar vertebrae. Photo taken by Elizabeth Weiss at San Jose State University.

In determining whether a fracture is the result of accidental or intentional injury, anthropologists consider several factors, such as location, type of fracture, and secondary causes of injury (Jurmain, 1999; Lovell, 1997). Pathological fractures are those that occur when normal pressure is applied to bone, but the bone is weak due to disease, malnutrition, or other causes. Traumatic fractures can be the result of accidents or aggression (Larsen, 1997; Lovell, 1997; Walker, 1997). Sharp object fractures are rarely noted in bioarchaeological remains since knife cuts and other slicing instruments cuts are easy to miss on bone and can be mistaken for post-mortem fractures caused by archaeological tools. Projectile injuries occur when projectiles, such as obsidian flakes, are embedded in bone (Figure 5.2). Dislocations occur when trauma may force a bone out of normal articulation; this is most common in adults since un-fused epiphyses of subadults usually result in the separation of the bone and in older adults bones are brittle and usually break rather than dislocate, such as when older people break their hip bones. Fractures can be described as complete, which is when the bone is broken in two separate parts; incomplete, which is when breakage and bending occurred; splintered (also known as comminuted); and compressed (also known as compound) (Lovell, 1997). The bone afflicted may indicate whether an injury is accidental or intentional. Head and face locations are the most common targets of intentional violence (Lovell, 1997; Walker, 1997; Weiss, 2006b). Forearm fractures may result from defending oneself against a strike (i.e., parrying fractures) or from falls (Jurmain, 1999). Accidental injuries appear more randomly and can relate to the environment (Lovell, 1997).

Not surprisingly, interpersonal aggression is the most commonly published type of injury. This is likely due to the high levels of aggression in prehistory and proto-history, but also may be the result of the ability to include larger samples, focus on patterns rather than just case studies, and tell a more interesting story. Evidences of accidental injuries are published in far fewer articles, but accidental injuries can reveal much about a population as well.

5.2. ACCIDENTAL AND ACTIVITY-RELATED FRACTURES

One of the most famous studies published on accidental injuries is the Neanderthal study by Trinkaus and Zimmerman (1982) who noted that Neanderthal remains had patterns of injuries that resembled rodeo workers. Their conclusions about the high frequency of forearm, rib, and other injuries visible on Neanderthal skeletal remains were that Neanderthals were victims of living and hunting large wild animals; they were being kicked and stomped by large animals similarly to the rodeo workers who were faced with being kicked and stomped by horses and bulls. Trinkaus and Zimmerman, further, noted that some of these injuries led to lifelong disabilities and the fact that these Neanderthals survived certain injuries implied that they had a community who tended to their injured.

Another study that analyzed fracture patterns and related them to non-violent causes comes from a late medieval population from Serbia. 861 individuals were examined and compared to skeletal populations who are known for their high levels of interpersonal aggression (Djurić et al., 2006). In this study, fractures were uncommon, but the fibula and the ulna were most often fractures. The ulnar fractures were likely the result of twisting forcing that were encountered during work activities. Although the ulna is often fractured in parrying blows to the head, some ulnar fractures can be the result of accidents (Jurmain, 1999). It appears that roughly half of the ulnar fractures in the Serbian population were due to violent encounters and the other half were due to accidents. Although there were cranial fractures that were suggestive of combat, the frequency was very low compared to other populations. In sum, it seems that the Serbian fracture frequency and pattern resembled that of British and Austrian samples of the same period rather than high-aggression sites, such as Nubia. The rural community of Serbia engaged in farming and most injuries were likely a result of labor intensive work, but interpersonal aggression was not completely absent from the culture.

Domett and Tayles (2009) looked at adult fractures in prehistoric Thailand (2000–400 BC) and also found evidence of interpersonal aggression (in bones of the hands and forearms), as well as accidental injuries that seem related to subsistence patterns. In a sample of nearly 300 adults, they found that over time long bone fractures increased and that this increase can be related to an intensification of rice agriculture. Ulnar and radial fractures increased throughout time and although this may relate to aggression Lovell (1997) points out that parry fractures usually result in transverse fractures and fractures that result from falls are often oblique or spiral. Domett and Tayles found that the majority of the radial and ulnar fractures were of the accidental typology and may be related to falling in the fields and to land clearing.

The absence of trauma on children is often noted in the bioarchaeological record, but Jimenez-Brobeil and colleagues (2007) found evidence of injuries in populations occupying Iberia from 900 to 1700 AD. They noted that, in the Argar culture that lived in small villages on steep hills with fertile valleys, several children had evidence of fractures. In all the remains (N = 123), no cranial trauma was found, but a clavicle fracture, a humeral fracture, and a femoral fracture among a few other post-cranial fractures were discovered. It appeared that the most likely cause of these fractures includes falling due to the rugged terrain; perhaps one child fell from a tree. Interestingly, the population that occupied the most rugged terrain also

had the highest incidences of fractures. It appears that children are protected from intentional injuries in past populations.

5.3. EVIDENCE OF VIOLENCE AND ITS ROOTS

Anthropologists have been interested in trauma resulting from interpersonal aggression for decades since it seems that human societies are prone to violence in a variety of forms from domestic fights, street gang fights, tribal conflicts, and even multinational wars. Violence and the evidence of violence are human universals. Ethnographies can provide evidence of violence both in Western and nonwestern cultures (e.g., Chagnon, 1992; Turnbull, 1987). From past populations, anthropologists have evidence of violence in murals and other forms of art that depicts the lives of past populations (e.g., Buzon and Richman, 2007). However, the clearest evidence of interpersonal aggression is found on the skeletons of victims of violence. Case studies on individuals who have been victimized can be of interest, such as Powers' (2005) examination of an individual from medieval London with three cranial injuries (likely the result of battle trauma) that were treated and partially healed. Some case studies provide the initial evidence of violence in certain areas or temporal periods, such as Dawson and colleagues' (2003) find of an adolescent male with fractures on the left side of his skull from Israel at around 4000 years ago. A case study from Mississippi has also been utilized as an example of the documented conflicts during times of European contact around 1640 AD to 1814 AD (Hogue, 2009). Finally, a case study of two skulls from Italy with dates of 940–725 years ago raised questions of whether hammer tools had earlier origins than previously assumed (Facchini et al., 2008). Although these and other case studies are of interest, many anthropologists now examine population frequencies and types of trauma to reconstruct past patterns of violence and determine whether cultural or evolutionary factors affect these patterns.

A good example of a population study on trauma comes from Nubia. It appears that Egyptian policies toward Nubians were aggressive to try to overtake their land (Buzon and Richman, 2007; Judd, 2006). Nubian remains have high trauma frequencies during the Middle Kingdom (2050–1650 BC) likely due to Egyptians' use of armed aggressive tactics to suppress Nubian populations located in Kerma. By the New Kingdom (1550–1050 BC), Egypt had succeeded in colonizing nearly all of Nubia and their mechanisms of control turned peaceful (Buzon and Richman, 2007). Patterns of injuries reveal that there was a decrease in victims of violence from the Middle Kingdom to the New Kingdom, which supports the cultural shift from military to diplomatic actions (Buzon and Richman, 2007; Judd, 2006).

California Amerinds have also been studied to determine evidence of population trauma patterns (Jurmain, 1988; 2001; Jurmain and Bellifemine, 1997; Jurmain et al., 2009; Weiss, 2006b). Evidence of craniofacial trauma, parry fractures, and projectile wounds in large samples reveal high levels of violence in pre-contact California. Evidence of violence increased in Bay Area and Southern California populations that may have resulted from environmental stresses (Jurmain et al., 2009; Walker, 1989). The increase in violence may relate to unstable environments that caused an intensification of competition for resources. Climatic changes have been known to adversely affect populations, even when populations do not engage in agriculture and live in resource-rich environments (e.g., Weiss, 2002).



Figure 5.3. An example of a healed broken nose in a prehistoric California male. Photo taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.

Although entire skeletal analyses are useful in identifying violence patterns, anthropologists have found non-lethal craniofacial injuries to be of particular interest; these injuries lack the complications of possible post-mortem damage. Anthropologists, furthermore, have linked craniofacial injuries, especially of nasal bones (Figure 5.3), to interpersonal aggression with other, less-probable factors (such as falls) (Judd, 2004; Jurmain et al., 2009; Keenleyside, 1998; Lessa and De Souza, 2004; Standen and Arriaza, 2000; Walker, 1989, 1997). Even parry fractures, which are mentioned above as good indicators of interpersonal aggression, can be caused by accidents (Jurmain et al., 2009). Thus, anthropologists often use evidence of craniofacial trauma to reconstruct cultural rituals or struggles, such as in shifts of sports' popularity, subsistence pattern differences, the struggle for resources, and general warfare between groups (Cybulski, 1999; Keenleyside, 1998; Lessa and De Souza, 2004; Powers, 2005; Lessa and De Souza, 2004; Owens, 2007; Paine et al., 2007; Standen and Arriaza, 2000; Steadman, 2008; Walker, 1989, 1997).

In many studies on interpersonal aggression, anthropologists connect causes of trauma to culturally specific explanations. Cultural-specific studies are of great interest and informative for understanding past populations. Cultural-specific studies often provide unique insight to specific periods and causes of violence, such as the popularity of sports, warfare, and changes in environmental pressures. Lessa and de Souza (2004), for example, addressed issues of increasing violence in Chile during a period of expanding chieftainship of the Tiwanaku in a desert environment. In another example from Chile, Standen and Arriaza (2000) attribute trauma patterns in Chile to quarrels over resources or possibly mock/ritual fights. Keenleyside (1998) discussed the differences between trauma levels between Aleuts and Eskimo; he concludes that the Aleut have higher levels of trauma in part because island living lacks the amount of resources compared to coastal living. Owens (2007) examined craniofacial trauma in pre-European contact in 896 Canary Island natives and found evidence of trauma was abundant, especially among males and adults. The type of trauma implies that the Canary Island inhabitants used clubs as their main weaponry. Finally, Paine and colleagues (2007) attribute the high level of cranial trauma among males of agricultural Italy in the 5th and 6th Centuries to protecting land resources, which was a male task in these patrilineal communities.

Table 5.1. Rates of craniofacial trauma by sex in California CA-ALA-329 hunter-gatherer population. Note the sex difference in trauma location.

Bone	Males	Females
Frontal	4	0
Mandible	1	1
Maxilla	0	0
Nasal	3	0
Occipital	1	2
Parietal	2	0
Temporal	0	0
Zygomatic	1	0
Total	12	3

The number of individuals with crania that were examined was 97; out of these 97, 11 had injuries (some had multiple injuries).

In addition to the cultural specific explanations offered by many anthropologists, there are general trends that may have an evolutionary explanation (e.g., Knauft, 1991; Weiss, 2006b). Anthropologists have previously addressed these issues in human and non-human populations (e.g., Knauft, 1991; Lovell, 1991; Martin and Frayer, 1997; Weiss, 2006b). Knauft (1991), for example, has found that ape behavior leading to violence and trauma differs qualitatively from human violence; apes have a male hierarchy and dominance-driven violence that is absent in humans. Or perhaps the human violence is just a more complex form of ape violence.

In human skeletal samples, researchers studying a variety of cultures have noted the higher incidence of trauma in males than in females (Keenleyside, 1998; Lessa and De Souza, 2004; Owens, 2007; Paine et al., 2007; Standen and Arriaza, 2000; Walker, 1989, 1997; Weiss, 2006b); this is especially true for frontal facial and cranial trauma. Table 5.1 provides an example of higher trauma rates in males compared to females from a California hunter-gatherer population. This sex difference trend may relate to specific cultural aspects, such as adult males engaging in warfare to protect resources whereas females would not engage in this act (e.g., Paine et al., 2007). However, there may be an evolutionary basis, which can be derived from the same trends being seen in non-human primates, such as howler monkeys, red colobus monkeys, chimps, and gorillas (DeGusta and Milton, 1998; Jurmain, 1989; Jurmain and Kilgore, 1998). Non-human male primates experience higher trauma than females. There are exceptions to the high male violence; an exception in humans comes from Steadman (2008), who found that females and males were as likely to be victims of violence in a prehistoric Illinois population (1150–1250 AD). That may relate to increasing complexity of societies and chiefdom states arising. Additionally, in many skeletal samples, male injuries are consistently in the front of the face or on the front of the mandible, which implies a face-to-face combat. This pattern is found in human populations (e.g., Keenleyside, 1998; Lessa and De Souza, 2004; Powers, 2005; Standen and Arriaza, 2000; Walker, 1989, 1997; Weiss, 2006b) and in non-human populations (e.g., DeGusta and Milton, 1998; Jurmain and Kilgore, 1998). The sex-difference pattern noted suggests higher male aggression with an equal amount of violent activity on the injured and presumably the injurer. When females experience trauma, it is often to the back of the head, which some anthropologists have

related to females being victims rather than aggressors (Cybulski, 1999; Weiss, 2006b). Sex differences are often biological in nature and testosterone has been implicated in aggressive behavior (Aromäki and Lindman, 1999). Thus, although different cultures may have varying degrees of sex differences, it appears that the higher male facial trauma is related to an evolutionary adaptation. Females were most likely selected to avoid risk and aggression, which could put them and their offspring in jeopardy. Sexual selection could also increase male aggression if females are choosing aggressive males who would fight for access to resources.

A low incidence of trauma among very young individuals has also been a noted trend. Anthropologists have found this age pattern in various populations from various cultures (Judd, 2004; Lessa and De Souza, 2004; Owens, 2007; Paine et al., 2007; Standen and Arriaza, 2000; Steadman, 2008; Walker, 1997; Weiss, 2006b); the same age pattern appears in non-human primates as well (DeGusta and Milton, 1998; Jurmain, 1989; Jurmain and Kilgore, 1998). Since this pattern is found regardless of culture or location, one can hypothesize that adults are more likely to be violent or engage in interpersonal aggression than subadults. This pattern makes sense from an evolutionary perspective; it would be disadvantageous for the youngest individuals to become injured and perhaps die before they have to reproduce. Selection for protection of young, such as maternal care, may be one reason that we do not see as many facial injuries in subadults than in adults. Another possibility is that injuries that occur in early years are no longer visible or that throughout a longer life individuals have more time to get into altercations. There are exceptions to the protection of young – the Anasazi populations who engaged in cannibalism often had young victims (Larsen, 1997). Additionally, Peruvian sacrificial victims were often young as well, which may be linked less to interpersonal aggression and thought of as an honor to be sacrificed to the gods. Often, prehistoric populations also tried to heal those injured through surgery.

5.4. SURGICAL PROCEDURES

Surgical procedures in prehistory have been documented as case studies that include descriptions of 3600 year-old amputations from Israel (Bloom et al., 1995); foot amputations in the New World with prosthetic wooden feet during the Moche culture (AD 100–750); proper alignment of fractures world wide (Larsen, 1997); and dental surgery that includes drilled teeth (Shwartz et al., 1995). These medical procedures and others indicate that prehistoric populations tended to their people and knew the importance of healing wounds and bringing people back to independence. The most common form of prehistoric surgery is called trepanation (or trephination). Trepanation comes from the Greek word to drill and is a form of cranial surgery that involves opening the cranial cavity (i.e., making a hole in the cranium) (Figure 5.4). Cases of trepanation have been documented from Poland, the Czech Republic, India, England, Germany, Israel, Peru, Iberia, and many other locations (Liesau Von Lettow-Vorbeck and Pastor Abascal, 2003; Lorkiewicz et al., 2005; Mays, 2006b; Mogle and Zias, 1995; Sankhyan and Weber, 2001; Smrčka et al., 2003; Verano and Andrushko, 2008; Weber and Wahl, 2006). Trepanation is the oldest form of surgery documented and may date back as far as 7000 years ago (Weber and Wahl, 2006). It is most often reported in

adults and more often in males than females, but cases of sub-adult trepanation have occurred, such as a sub-adult in Israel with a possible case of scurvy who had undergone trepanation and died (Mogle and Zias, 1995).

Reasons for trepanation seem to be varied and magical or religious reasons may have played a part in trepanation activities. Some anthropologists find that cranial trauma is correlated with trepanation, which suggests that the operation was done as a healing method from trauma or other ailments (Andrushki and Verano, 2008; Mays, 2006b). Nevertheless, there are other cases where no other pathologies or trauma are present and the reason for the surgery remains elusive (Weber and Wahl, 2006).

Some of the most interesting aspects of trepanation are the fairly high survival rates and the low infection rates. In Peru, a study from Andrushko and Verano (2008) pointed out that trepanation found at six sites dating from 200 BC to 1532 BC showed increases in survival rate to nearly 90% and very low infection rates; it appears that methods had become quite uniform and, thus, successful. The site of the trepanation is important in the survival rate; location is usually far from cranial sutures since the bone is thickest at the suture lines (Mogle and Zias, 1995). Another interesting aspect of trepanation is that many individuals underwent multiple surgeries (e.g., Andrushko and Verano, 2008; Liesau Von Lettow-Vorbeck and Pastor Abascal, 2003; Sankhyan and Weber, 2001). Low infection rates and high survival rates were likely related to the short duration of the surgery, the small size of many trepanations, and tools that were freshly knapped (and thus nearly sterile) (Weber and Wahl, 2006). It is possible that natural antibiotics were also utilized, such as certain mushrooms (Weber and Wahl, 2006). Finally, it is important to note that sometimes different causes, such as sword cuts and post-mortem damage, can be confused with trepanation (Weber and Wahl, 2006).



Figure 5.4. A female skull that was trepanated dated around the Neolithic (3500 BC); the patient survived. Natural History Museum, Lausanne. Photo provided by Rama.

5.5. CHAPTER SUMMARY

Trauma can occur for a variety of reasons. Anthropologists determining the causes of trauma take into account several factors that include who was injured, where on the body injury occurred, and environmental factors that may lead to injuries. Prior to determining the cause of trauma, anthropologists must be sure that the trait be noted as trauma occurred before death or at the time of death. Antemortem (before death) injuries usually show signs of healing; if healing is complete, some of these injuries may be overlooked and some cannot even be detected without radiographs. Perimortem fractures that occur near the time of death or may be the result of death are more difficult, but not impossible, to distinguish from post-mortem (after death) injuries. Upon determination that the fracture did not occur after death, anthropologists then set out to determine the cause of the fracture. Trauma can be a result of weak bone from illness or dietary deficiencies; when trauma occurs on weakened bone, then these fractures are named secondary traumas. Primary traumas occur on healthy bones. The causes of primary trauma can be accidental (such as falls where there is ice on the ground) or intentional. Intentional trauma displays some cross-cultural patterns that suggest evolution has selected for behavior that protects the young and females; these patterns of higher male victims and lower pre-adult victims can be found in non-human primates too. Evolutionary speaking, it would not make sense for individuals who have yet to have children to die, and women are needed for having more children and take care of those who are living. Besides accidental and intentional trauma, anthropologists have found evidence for prehistoric cranial surgery called trepanation around the world. Some anthropologists have argued that these surgeries were intended to alleviate pain caused by cranial trauma whereas others have pointed to additional purposes that may include religion. It is interesting to note that the survival rate of trepanation was high, especially considering that modern sterilization techniques were not utilized.

Key Terms

- Accidental Injuries
- Antemortem
- Callus
- Comminuted Fractures
- Compound Fractures
- Evolutionary Trends
- Dislocation
- Interpersonal Aggression
- Parry Fracture
- Perimortem
- Post-mortem
- Primary Trauma
- Projectile Injury
- Pseudoarthritis
- Secondary Trauma
- Trauma
- Trepanation/Trephination

Chapter Questions

- 1) How does an anthropologist determine whether a fracture occurred before or after death?
- 2) How does a misaligned healed fracture occur?
- 3) What is the difference between a complete and incomplete fracture?
- 4) At which age do dislocations occur most and least and why?
- 5) What types of fractures are commonly seen in interpersonal aggression cases?
- 6) What are some environmental causes of trauma?
- 7) What are some cross-cultural trends in trauma and how can these trends be explained?
- 8) What are some of the reasons given for the success rates of trepanation?

CULTURAL MODIFICATION: AESTHETICS OF THE PAST

6.1. INTRODUCTION TO CULTURAL MODIFICATION

Modern cultures engage in a variety of rituals and practices that change the appearance of individuals: tattooing, ear-piercing, and cosmetic surgery are all types of cultural modification. For the most part, cultural modification of appearance does not affect the bones in modern populations (however there are exceptions, such as with cosmetic surgery). Due to the overall superficial nature of cultural modification, we do not have much evidence of this type of history from the past. Nonetheless, tattooing has been a practice for at least five-thousand years in the Alps, we know this from a mummified male with tattoos dating to that period. Also, use of cosmetics and piercings have been found in ancient Egyptian mummified remains. For skeletal indicators of modification, there are dental and cranial practices that can be found around the world.

Table 6.1. Types of dental modification as outlined by Romero 1970

Type/File Location	Variation within file location		
Edge of Dental Crown Filed	A: Occlusal edge only	B: One crown angled filed	C: Both crown angles filed symmetrically
Labial Surface of the Crown Filed	D: Straight filed lines appear on labial surfaces of the crown	E: Incrustations of pyrite, jadeite, turquoise, or gold; or whole labial surface filed	
Both Edge and Labial Surface Filed	F: both occlusal edge and angles of crown are altered asymmetrically	G: Alterations of occlusal edge or angles of crown plus incrustations (e.g., gold)	

6.2. DENTAL DECORATION

Anthropologists have documented intentional dental modification in living and past populations all over the world (see Arcini, 2005; Finucane et al., 2008; Ubelaker, 1989). Anthropological investigations have pointed to dental modification having its peak between 700 to 1400 AD (Arcini, 2005). Dental modification is most frequently found in the New World, but Old World finds are some of the oldest documented (Finucane et al., 2008). Prior to 2005, there were no published documents on dental modification in Europe (Arcini, 2005). Although intentional dental modification can sometimes be mistaken for unintentional modification, such as when teeth are chipped due to injuries or grooved due to tool use and “toothpicks,” patterns of intentional modification can be identified by location on the tooth, distribution in a population, and consistency in style. When dental modification is identified, it is used to understand past cultures with consideration to modern cultures and their reasons for dental modification (Finucane et al., 2008). Buikstra and Ubelaker (1994) and Ubelaker (1989) suggest using the classification system from outlined by anthropologists Romero in 1970. In this classification system, modification is split into 59 types; they differ in location of modification, shape of modification, and whether an inlay was likely or not. Table 6.1 lists some of the different types of dental modification and their characteristics. Intentional modification is nearly always found on the incisors and canines since these teeth are most visible; Figure 6.1 is a good example of dental modification on the incisors and canines, which appear to have been deliberately carried out for aesthetic purposes. Plus, unintentional modification or treatment of pain is often paired with dental pathologies whereas modifications for cultural purposes are performed on healthy teeth. Two interesting articles published on dental modification from the Old World help to illustrate the ways in which anthropologists examine and analyze dental modification.

Caroline Arcini (2005) published the first European evidence of dental filing. The sample consisted of 557 skeletons of Vikings dating from 800 to 1050 AD found in five sites across southern Sweden. Twenty-two individuals were discovered to have dental modification of incisors that appeared to have been created through filing. All the filed teeth belonged to young males and were not associated with dental pathologies; additionally, it seems unlikely that injuries or tool use were the cause of these dental changes since all the changes occurred only in males, only on the labial surface, and were horizontal for the most part. Experimental tests demonstrate that these changes can be made with a file and that it would take about 20 minutes to make marks similar to those found in the Vikings. The purpose of these markings is difficult to deduce since we have no modern day comparisons for the region; perhaps it was to show courage.

In Africa, dental modification is still prevalent in many tribes; ethnographic descriptions of dental modification and their purposes are abundant (Finucane et al., 2008). Some of the causes include taking on the fierceness or courage of animals, such as in teeth filed to points, or as rites of passage, or even required rites prior to child bearing. Different tribes engage in different styles of filing and modification. Also, different groups of people are affected; in some tribes, females have their teeth filed while in others the males experience the modification. Finucane and co-workers (2008) documented dental modification in a West African site that dates to the Late Stone Age (about 4500 to 4200 years ago) in a poorly preserved sample of eleven individuals. These remains from Mali show pointed incisors that

are similar to some modern African tribes; interestingly, young females displayed the modification. In comparison to modern African tribes, the causes may be to show courage, as a rite of passage, or just done for aesthetic purposes. Whatever the cause, this extends the evidence of modification of teeth to West Africa and provides an early date for modification on the African continent.



Figure 6.1. Monte Albán - Museo del Sitio. Skull fragment with filed teeth. By Wolfgang Sauber. Date Created: 24.03.2008.



Figure 6.2. Skull deformed for aesthetic reasons. Phase II of San Pedro de Atacama Culture (260–300 CE). Southern Andes, Chile. Accession number Inv. 76/1/131. Photographer/source Luis García (Zaqarbal), 06–April–2008.

6.3. CRANIAL DEFORMATION

Artificial cranial deformation, possible due to the pliability of cranial bones during infancy, has been documented throughout the world (e.g., Ricci et al., 2008; Del Papa and Perez, 2007; Rhode and Arriaza, 2006; also see Ubelaker, 1989); Figure 6.2 illustrates one variation of cranial deformation. Cultural practices that require modification for aesthetic reasons have been published for the Andean coast and other regions (Buikstra and Ubelaker, 1994; Ubelaker, 1989), but cultural causes of cranial modification may be unintentional as well (Ricci et al., 2008; Ubelaker, 1989). Cradle boarding, for example, is the act of tying an infant to a board for transport and results in a flattened posterior skull (Ubelaker, 1989). Anthropologists have examined prehistoric cases of artificial cranial deformation in order to determine causes, reconstruct cultural practices, and aid in determining which cranial traits used to retrace biological relationships can be affected by this environmental impact (Del Papa and Perez, 2007; Ricci et al., 2008; Rhode and Arriaza, 2006).

Different types of cranial deformations result in different head shapes. The types of deformation that have been described can be divided into five groups: 1) Vertico-Occipital, which is the simplest type of deformation and consists of flattening the lower occipital region only; 2) Lamboid, which flattens the posterior crania but further up than occipital and results in the lower occipital to seem to be protruding; 3) Frontal, which is when only the forehead is flattened and there was no pressure on the back of the head; 4) Fronto-occipital, which is caused by pressure on both the front and back of the skull and can be the result of two-boards being utilized; and 5) Circular, which is the result of binding (Ubelaker, 1989). There are variations within each of these categories and the pressure placed on certain areas can affect cranial and facial bones in a variety of ways (Del Papa and Perez, 2007). In general, Vertico-Occipital and Lamboid deformation seem to be unintentional cultural deformations caused by the use of cradle boarding. Whereas, the Frontal pressure may result from activities, such as carrying loads with a band across the frontal bone and the load being behind the body, but this is only likely if the activity was started in early childhood years and, thus, is often described as intentional. The last two methods (Fronto-occipital and Circular) seem to be cultural practices that are done for aesthetic purposes or due to other cultural reasons (Ricci et al., 2008; Ubelaker, 1989).

The most common geographical locations for evidence of cranial deformation occur in the Andean coastal region. Due to the high interest of the origins of populations in South America, anthropologists have been interested in determining the effects of cranial deformation on cranial traits that are used in determining biological relationships. Two studies recently published have provided evidence that cranial deformation does indeed interact with other cranial traits. Rhode and Arriaza (2006) examined the influence of cranial deformation on facial bones in prehistoric South Central Andeans. This study focused on the facial bones since researchers sometimes use only facial bones to avoid complication with deformations making the assumption that facial bones are not affected by deformation. Using nine measurements and a three score classification of deformation, the authors found in a sample of 350 crania that, out of the nine measurements, only three measurements were not affected by deformation in males and four measurements were not affected by deformation in females. These results suggest that many studies that have attempted to retrace biological relationships with crania that displayed some deformation by looking at the facial bones may

need to be reconsidered. In another study by Del Papa and Perez (2007), cranial vault deformations and non-metric cranial traits were examined to determine whether the non-metric traits were influenced by the deformation. The authors examined crania from Patagonia, Cuyo, and Northwest Argentina and noted that cranial deformation was particularly widespread in the Americas during prehistory. They utilized twenty-two non-metric traits that other anthropologists have often used for reconstructing biological relationships and analyzed cranial deformation through geometric morphometric computer analyses that allowed them to assess the degree of deformation. The authors found that the greater the degree of deformation, the more likely the non-metric traits would be affected. Additionally, traits that develop during the postnatal period and in areas of maximum growth are most altered by deformation; wormian bones (which are extra bones created by complex suture patterns) are particularly sensitive to deformation. They add that being able to distinguish which traits are affected most can help anthropologists make informed decisions about the traits they will use to reconstruct biological relationships.

An article from Ricci and coworkers (2008) examined evidence of cranial deformation in the Old World. In a Southwestern Libyan site dating to about 3500 years ago, three skulls displayed cranial deformation that appears to be of the Fronto-Occipital variety; this is the best documented evidence from prehistoric central Sahara. The authors also found a correlation with artificial cranial deformation and wormian bones (as others have documented). Interestingly, there is a dearth of evidence on cranial deformation in the ethnographic and bioarchaeological literature in Africa and especially in this central northern African region; here, cranial deformation is sporadic and hard to track. Their data, the authors suggest, tie deformation into distinct cultural practices that were not widespread, although modern African populations in the Sudan (and in the Congo of Sudanese immigrants) currently practice cranial deformation.

6.4. CANNIBALISM

Cannibalism is the act of humans eating other humans. Anthropologists have discussed the possibility of cannibalism in prehistory for decades. Rumors of cannibalism have circulated in the ethnographic literature, too. The required evidence for cannibalism has, however, been outlined only recently. Anthropologists Tim White and Christy Turner have been the two foremost experts on identifying cannibalism in the bioarchaeological record; they, too, have set the standards for identifying cannibalism. Since calling a people cannibalistic or suggesting a past culture practiced cannibalism is highly sensitive due to our modern morals concerning cannibalism, the evidence required to make these judgments is extremely rigid.

Anthropologist Hurlbut (2000) reviewed the modification of bones in the America Southwest to determine whether the evidence for cannibalism among the Anasazi, who occupied Colorado, New Mexico, Arizona, and Utah from 400 to 1350 AD, has been solidly proven. Hurlbut follows Turner's and White's methodologies and points out the traits one looks for in remains to determine whether cannibalism occurred. The basic concept is simple when human bones are treated like non-human animal bones then cannibalism may have occurred. The vast amount of evidence to determine this requires much examination. It is

important to have knowledge of the site context to know where the remains of humans and other animals were buried. Additionally, a minimum of six taphonomic (which is the study of what happens to organisms after they have died) characteristics are needed for identifying cannibalism: 1) perimortem breakage; 2) anvil abrasions; 3) cut marks; 4) burning; 5) under representation of vertebrae; and 6) pot polish. Perimortem breakage is breakage of bone right at death or right after; it bears certain distinct traits from post-mortem breakage as mentioned in chapter 5. Perimortem fractures tend to be spiral (since the bone is not brittle yet) where as post-mortem breaks tend to be transverse. Perimortem breaks also have bone fragments still adhering to the bone and the edges of the broken bone will be the same color as the exterior bone. Perimortem fractures, of course, can occur through non-human means, such as carnivore bites, but these usually display more perpendicular notches and fewer notches than when a human breaks a bone with a tool. Anvil abrasions are seen as striations that result from cutting the bone. The cuts are parallel scratches on the surfaces of bone. Other types of scratching can occur, such as trampling marks, but that is why more than one diagnostic is required for determining whether cannibalism occurs. Cut marks are usually produced by sharp tools against the bone and produce v-shaped slices. The location of the cuts are also important, since cut marks on only the crania would appear to be evidence for scalping rather than cannibalism. Evidence of cut marks in cannibalistic sites should be throughout the skeleton and related to disarticulating the skeleton. Burning is variable, but when in conjunction with pot polish (a white polish that bones take on when cooked in certain pottery), then cannibalism is more likely. Missing vertebrae is the final trait, which is due to the grinding of vertebrae for the fat in the bones that could be consumed as a soup.

In the review by Hurlbut, there is evidence for cannibalism in each Anasazi site she examined (which included 30 sites). All of these sites met the rigid criteria for cannibalism; whether this cannibalism occurred due to hunger, ritual, or other reasons remains unclear. Some anthropologists, Hurlbut argues, deny the evidence and look for other ways to explain the treatment of remains like other faunal remains. Violence and warfare, she said, can be ruled out since the demographics of these sites do not match up to those of warfare and violence sites (which is more males than females and an exclusion of very young individuals). Also, the claim that these individuals who were treated like animals may have been victims of witch-hunts cannot be ruled out, but rather does not exclude the possibility of cannibalism either. Finally, mortuary practices throughout the world tend to try to preserve the remains and distinguish them from the refuse of other animals; thus, it seems unlikely that the Anasazi would be the exception to this rule. Anthropologist Lambert and colleagues (2000) also examined cannibalism in Anasazi sites located in Southern Colorado that were abandoned abruptly in 1150 AD. Four sites provide evidence of the same nature that Hurlbut (2000) discussed, but there was also evidence of additional violence and, as mentioned above, abrupt abandonment of the sites. The authors suggest that violent raids that were followed by cannibalism can explain the mutilated corpses they found. Some of the evidence that they put forth are that the remains were heavily fractured, vertebrae were missing, cut marks were present, and breaks appeared to be perimortem; the only evidence lacking was pot-polish. The sites contained young individuals (for example a 7-year-old) as well as adult males and females. Environmental evidence suggests a possible clue to the reason behind the cannibalism; Lambert et al., point out that there appeared to be a drought that coincided with the locations and dates of these sites. Thus, cannibalism may have been a way to relieve

hunger. Even though the Anasazi may provide the best argument for the existence of cannibalism, other locations have been tested for cannibalism as well.

Ethnographic evidence of cannibalism comes most frequently from Oceania and more specifically Fiji (Degusta, 2000). Questions about the validity of these written accounts have arisen recently, and anthropologists are beginning to look for harder evidence of cannibalism on the islands. Examining a site that was occupied from AD 800–1100 to AD 1600–1800, anthropologist Degusta looked at human skeletal remains and non-human faunal remains to determine whether evidence for cannibalism was present. He divided the human sample into those which were buried and those found in the midden with the other animal remains, which included pigs, rats, dogs, and goats. By examining these skeletal remains, Degusta could determine whether the human remains were treated the same way as the non-human remains, which would support the argument for cannibalism. He found that the evidence for cannibalism was lacking since the modification of the human remains appeared far less frequently than for the other animal remains. Additionally, although the burials were less fragmentary, in other traits no differences appeared between the remains found in the midden and the remains that were buried. Degusta (2000), however, acknowledged at another Fijian site there appears to be stronger evidence of cannibalism.

Finally, early evidence of cannibalism comes from Spain on *Homo antecessor* remains that date back to 750,000 years ago. New evidence from the Bronze Age in Spain near the *Homo antecessor* site also shows signs of cannibalism. Anthropologists Cáceras and colleagues (2007) examined human remains found in a hole. Taphonomic analyses carried out revealed cut marks, human toothmarks, perimortem damage, and highly fragmented remains. It appears that the remains were actually buried by a later population, which suggests that the later population recognized the bones as humans. It is interesting that cut marks also appear on the vertebrae, and vertebrae are fairly numerous in this sample; nonetheless, the authors argue for an interpretation of cannibalism based on the rest of the evidence. One could contend that, due to the sensitive nature of the topic, perhaps cannibalism should be considered the last resort explanation. If human teeth marks are present, however, the only other explanation may be ritualistic cannibalism rather than gastronomic cannibalism. Anthropologists have argued that perhaps only ritualistic cannibalism has occurred (similar to Catholic symbolism of the flesh of Christ and the blood of Christ in communion).

6.5. CHAPTER SUMMARY

Perhaps the biggest challenges that lie ahead of anthropologists looking at cultural modifications, which include dental modifications, cranial modifications, and cannibalism, is trying to bring acceptance of “strange” and sometimes unthinkable acts and rituals to anthropologists of today. Cannibalism is controversial due to modern cultural viewpoints against cannibalism and we are apt to accept any explanation of the findings besides cannibalism. Perhaps if anthropologists view cannibalism through a more objective lens, then the extent of cannibalism can be more assuredly addressed. Anthropologists who study cannibalism have a rigorous benchmark for identifying cannibal sites; they require more data in support of their findings than perhaps any other topic in bioarchaeology. Due to the increase in body modification throughout the modern Western world, it may be argued that

cranial deformation and dental modification does not seem nearly as exotic as it once did. Dental modification, however, is not nearly as prevalent as cranial deformation that has been documented all over the world. Interestingly, cranial deformation also leads to changes in cranial traits utilized in reconstructing past biological relationships and, thus, anthropologists are attempting to figure out which traits are least affected by these deformations. Once anthropologists can determine the traits that are tightly under genetic control, even when deformations take place, then reconstructing evolutionary family trees will be improved.

Key Terms

Artificial Cranial Modification
Anvil Abrasions
Cannibalism
Cradle Boarding
Dental Modification
Filed Teeth
Frontal
Lamboidal
Occipital
Pot Polish
Taphonomic
Wormian Bones

Chapter Questions

- 1) What types of dental modification have been documented in the bioarchaeological record?
- 2) How many types of dental modification exist?
- 3) How can cranial deformation affect biological relationship studies?
- 4) Where do we have the highest degree of cranial deformation?
- 5) What are the different cranial modification types?
- 6) Why is the study of cannibalism controversial?
- 7) How does an anthropologist decide whether there is evidence for cannibalism at a site?

DIET: FOODS OF PAST POPULATIONS

7.1. INTRODUCTION TO TECHNIQUES USED TO RECONSTRUCT DIET

Diet is a topic of interest to many researchers since dentition is extremely durable and often well-preserved. Additionally, diet often leads to clues about the environment and how prehistoric inhabitants utilized their surroundings. Diet gives clues to health, status differences, and cultural practices, such as weaning. There are numerous ways to reconstruct diet and any single bioarchaeology textbook may be deficient in describing all the research trends in reconstructing diet. Some methods include analyses of coprolites (e.g., Reinhard et al., 2007); malocclusion (e.g., Turner, 1979); dental microwear (e.g., Mahoney 2006; El-Zaatari, 2009); craniofacial morphology (e.g., Sardi et al., 2006; Spencer and Ungar, 2000); occlusal wear (e.g., Arnold et al., 2007; Bernal et al., 2007; Eshed et al., 2006); and isotope frequencies (e.g., Prowse et al., 2008; Waters-Rist and Katzeberg, 2009). The most commonly published of these are occlusal wear, craniofacial morphology, and isotopic analyses.

Coprolite (which is the scientific name for fossilized feces) evidence has been much ignored in the bioarchaeological literature, but as remains get re-interred using federal and state laws to remove skeletal remains from collections, coprolite evidence may be of growing importance to reconstruct the past. Anthropologists Reinhard and colleagues (2007) reviewed a variety of coprolite evidence from the Southwest US. They point out some of the difficulty in analyzing the data in order to reconstruct diet. One problem encountered is that preservation varies greatly due to how the food was processed, the intestinal environment, and the environment after defecation. Other problems are more easily overcome, such as establishing a standardized method for data collection so that sites can be easily compared to one another. The problem of deciphering whether the fecal matter comes from humans or other animals has already been worked out due to the distinct colors, odors, and different contents (such as parasites present) of coprolites depending on the origin of the feces. Upon the examination of the sites, Reinhard and co-workers discovered that all sites showed a high dependency of rabbit and rodent consumption; this is of interest because hunting is usually thought of in terms of larger game animals. Another aspect of the high consumption of small game is that females were likely to have engaged in these hunts as well as males. Thus, the authors have used coprolites to restructure our vision of hunter-gatherers and noted the importance of small animal food resources.

Malocclusion, which is when teeth do not have a perfect edge-to-edge bite, has increased over time. Even though a perfect bite is rare, severe malocclusion occurs commonly now. Reasons for malocclusion that have been highlighted in the anthropological literature include softer foods and the difference between the plasticity of bone versus the genetic control of dentition. Thus, it seems that our jaws are not getting as big and strong due to lack of use, but our teeth remain large and this leads to crowding, overbites, and under-bites. Some of the evidence comes from Japanese remains that have been tracked from the 1000–500 BC Jomon period through to modern Japanese (1964–1966); hunter-gatherers of the Jomon period experienced malocclusion around 20% of the time, whereas agriculturalists experienced the malocclusion nearly 50% of the time, and in modern Japanese malocclusion occurs around 76% of the time (Larsen, 1997). Other cases of increased malocclusion with a softer diet come from Pima Indians (Corruccini et al., 1983) and other Amerinds who switched over to agricultural subsistence from hunting-gathering practices (Larsen, 1997).

Scanning electron microscope analyses has been useful in examining paleoanthropological data sets. Anthropologists Patrick Mahoney (2006) utilized the same technology to determine how the shift from hunting and gathering to agricultural affected dental wear in Israel. Mahoney expected to find an increase in pitting of dentition due to the use of stone-ground foods, which would have added the abrasive quality to foods. Although the hunter-gatherers consumed wheat as well, Mahoney specifically mentions that the grinding use of mortars and pestles would have added more abrasives into the diet and that this would result in larger and more frequent dental pitting in the early farmers compared to the hunter-gatherers. In a sample of 30 skeletons from the Natufian period of hunter-gatherers and 30 skeletons from Neolithic farmers, Mahoney found that agriculture did indeed lead to a harder diet as predicted. The pressures are unevenly expressed in the teeth, which mean that there are facet differences on teeth in agriculturalists but not in the hunter-gatherers. Additionally, the diet may have required stronger bite forces, which may be why the changes in the agriculturalists are not seen in all the facets.

Examining a different type of data set available through the new computer advances. El-Zaatari (2009) examined occlusal microwear texture of hunter-gatherers. El-Zaatari points out that microwear texture analyses have been mainly conducted on non-human primates and paleoanthropological fossils, but that this technology can be used successfully in more recent hunter-gatherers. He notes that microwear texture analyses have nearly replaced scanning electron microscope analyses since the images of the tooth are more 3-dimensional and allow for more detailed analyses. These techniques require making molds of the dentition, which can be met with mixed results as El-Zaatari demonstrated in his paper with evidence of molds that were filled with bubbles or had scratches due to the tools utilized to clean the occlusal (biting) surface. Nonetheless, when problems with molds arise, the images are clearly distinct from any other tooth wear and, thus, can be removed from the analyses. El-Zaatari also mentions that the research that indicates different wear patterns for different teeth in a single individual, but notes that in his own data analyses this complication does not surface. Using a sample of 117 individuals from five sites that are varied in their diet, El-Zaatari attempted to test whether the occlusal wear would be distinct enough even when looking at different hunter-gatherers. The samples consisted of some almost exclusive meat eaters, such as the Tiagara of Alaska, the Fuegians of Southern Chile, and the Mediterranean Chumash, and some mixed diet hunter-gathers, such as two South African samples (one prehistoric and one historic) and an Andamese island sample. Results revealed distinct occlusal wear for all

groups. First, meat eaters had less wear than mixed diet hunter-gatherers, but within meat eaters those who preserved their meats in open environments that were subject to sand and other abrasives being blown into the food, such as the Tiagara, had far greater wear than the other meat eaters (who had the lowest occlusal wear). Fine striations were characteristic of the meat eaters who did not preserve their meats, whereas pitting was more common in mixed diet hunter-gatherers. El-Zaatari demonstrated the usefulness of this technique even within a subsistence pattern.

7.2. OCCLUSAL WEAR DATA

Occlusal (biting surface of teeth) wear of dentition has been utilized by anthropologists to reconstruct diet and non-dietary activities that affect the teeth (e.g., Arnold et al., 2007; Kieser et al., 2001; Minozzi et al., 2003; Molnar, 2008). Anthropologists have noticed for decades that skeletal remains from prehistoric sites have much greater wear on their teeth than industrial populations; additionally, they noticed that changes sometimes occurred in short time periods associated with dietary shifts, such as the adoption of agriculture, that implies these changes are driven by environmental rather than genetic factors. Overall trends noted by anthropologists include that hunter-gatherers in general have more wear than agriculturalists (e.g., Deter, 2009) and that hunter-gatherers seem to have more anterior wear than agriculturalists in particular, which is often associated with the use of teeth as a third hand (e.g., Molnar, 2008). Cross-culturally, teeth are affected in a similar way; for example, the last teeth to erupt (the third molars) are the least worn (e.g., Eshed et al., 2006) and flat wear proceeds cupped wear. Flat wear is often attributed to tough fibrous diets that increase the chewing power; other types of wear include inclined wear that may be a result of malocclusion (such as overbites and under-bites), different diets (such as coastal diets of shellfish), or a way to increase chewing when teeth are being worn down (Watson, 2008). A specific concern in the study of tooth wear is that changes that occur in food processing may actually change tooth wear even when diet has remained the same (Watson, 2008). Given the knowledge of these patterns and the added help of archaeological and isotopic analyses, tooth wear can be an efficient tool to reconstruct diet and sometimes tool creation.

Studies that have highlighted the changes in tooth wear as a reflection of diet have been published for decades; recent studies by Kieser and colleagues (2001), Arnold and colleagues (2007), and Deter (2009) support the role in diet on tooth wear and extend the findings to new populations and better samples with more refined methodologies. Kieser et al. (2001) examined the levels of tooth wear on 50 pre-contact Maori skulls from New Zealand. They set out to determine whether the high levels of abrasion (occlusal wear that is caused by foods) reported by early anthropologists would be found in late prehistoric populations of Maori compared to the previously published data on earlier prehistoric Maori populations (who had less severe dental wear). They examined the teeth macroscopically for degree of wear and whether wear was flat or inclined; additionally, the authors used scanning electron microscopes to examine the wear patterns. They found that males and females had the same degree of wear, which is what one would expect if diet caused the dental wear, but there was some difference in the degree of curvature in the wear between males and females (which may be due to sex differences in tooth size and mandibular shape or due to activities). They

also found that these late prehistoric Maori had more severe dental wear than reported in earlier prehistoric Maori, which may be reflective of a shift in diet. The early Maori diet seemed to consist of soft vegetation and meats whereas the later prehistoric Maori diet included shellfish (which are often gritty from the sands in their meat) and fern root, which is a tough, fibrous plant. Thus, we see that it sometimes takes dietary shifts without agriculture to change dental wear.

In the Ukraine, 208 teeth were studied for tooth wear in two ancient populations (dating from 8th to 10th Centuries AD). Arnold and coworkers (2007) point out that dental wear pattern studies have focused on North America, Africa, and the Middle East, while studies on European populations have been limited. They provide detailed examinations of dental wear along with dental pathologies to determine whether the hunter-gatherers (the Chervona Gusarovka population) experienced greater or less wear than the agriculturalists (the Upper Saltov population). The Chervona Gusarovka hunter-gatherers had a mixed diet in which they consumed meat, fish, and a small amount of cereals; anthropologists examining microwear and macrowear have noted that meat does not wear down occlusal surfaces as severely as cereals. The Upper Saltov agriculturalists, on the other hand, ate mainly cereals that were grated on granite or sandstone millstones. It appears that both populations had low caries rates, but the hunter-gatherers had less abrasion and more bone resorption. The agriculturalists had high levels of abrasion that may relate to the high consumption of cereals, low consumption of meats, or the millstones that would have added grit into their diet. Thus, it appears that in these European samples, unlike in North America, agriculturalists actually had greater occlusal wear than hunter-gatherers. This difference may be due to the high amount of meat consumed by the hunter-gatherers and, perhaps, they did not use their teeth as tools, as is evident in other hunter-gatherer populations.

In a 2009 study by Deter, North American samples (three late Archaic hunter-gatherer population dated at around 3400 years before present and a late Anasazi/early Zuni agricultural population dated at around 700 years before present) were utilized to test for changes in dental wear from hunter-gathering to agricultural subsistence. She notes that earlier studies have found hunter-gatherers to have higher levels of anterior and posterior dental wear compared to agriculturalists. Some of these studies point to activities, such as sinew preparation of the Inuit, while others have focused on diet, and still others look at food processing. With her sample of over 2000 teeth, Deter found hunter-gatherers had higher percentages of occlusal dentine exposed (the teeth were worn more) than the agriculturalists. These differences were present in the different age groups and on the different teeth; where the differences were not statistically significant, they were still in the same direction. She also found that, although hunter-gatherers and agriculturalists had different degrees of wear, the pattern of wear was similar for both populations (e.g., the third molar experienced the least wear), which she attributed to age at eruption. The hunter-gatherer wear was likely related to a combination of tooth use for tools, diet (especially sand from seafood, such as mollusks), and that the lack of food processing required more chewing forces.

Some tooth wear differences can be attributed nearly entirely to differences in food processing and not the types of foods consumed. Eshed et al. (2006), for example, looked at tooth wear at the advent of agriculture in the Levant and found that differences between Natufian hunter-gatherers (10500–8300 BC) compared to Neolithic agriculturalists (8300–5500 BC) were likely not diet related. The Natufian diet was based on hunting (mainly gazelles) and gathering (mainly cereals) whereas the Neolithic sites utilized domesticated

cereals and continued to hunt. Earlier studies that looked at the agricultural transition in the Levant had small sample sizes and information on dental scoring was scarce. Eshed and coworkers study tried to remedy the problems of previous samples by looking at 1,160 teeth from the Natufian hunter-gatherers and 804 teeth from the Neolithic agriculturalists. They all recorded their degree of wear in a detailed manner and examined dental pathologies. They found that wear in the Natufian sample is higher than in the Neolithic sample, but caries rates were similar. The high rate of tooth wear in the Natufian population supports other work on a general decline in tooth wear in agriculturalists, but since the diet remains overall similar in the Levant, the authors suggest that this shift related to the use of teeth as tools in the Natufian culture and in a greater degree of processing the foods in agricultural populations. Similar findings have appeared by Chattah and Smith (2006) who also looked at the Southern Levant and argued for the importance of food processing as a factor of dental wear rather than diet. In 2008, Watson looked at a completely different sample and noted that changes in tooth wear may relate to food processing, too. Watson examined samples from Northwest Mexico during the early agricultural period. He found that in the sample of 84 skeletons from the early agricultural period broken down into two phases (1600–800 BC and 800 BC–200 AD) dental wear had changed although diet had not. In general, it is assumed that these populations practiced a mixed subsistence economy that was stable over the entire early agricultural period. However, data show that wear from the later phase is greater than the earlier phase. This shift in molar occlusal wear seems to relate to an increase in the mechanical processing of food that increased dietary grit.

Evidence of non-dietary wear comes from Sweden and Libya. Molnar (2008) examined atypical wear and oral lesions in a Swedish sample dated to 2750–2300 BC. These Middle Neolithic Europeans consumed marine animals, such as fish and seals, as indicated by isotopic analyses. No use of cereals or domesticated animals existed. The atypical wear noted in the 764 teeth from 17 adult males and 11 adult females were studied using a binocular microscope and determined to have occlusal facets that were uneven in distribution of the teeth; excessive occlusal wear in the molars and premolars; and striations that occurred horizontally, vertically, and in-between teeth. Along with these types of wear, chipping, periapical lesions, and lingual tilting were also common. Females had higher labial striations, whereas males had greater bacterial periapical lesions. Also, chipping occurred in females more than in males for the incisors. It appears that both males and females engaged in using the teeth as a third hand, but that the effect of this differed slightly with males and females. The etiology for the wear may be the use of toothpicks for therapeutic reasons or the pulling of fibers between teeth. Minozzi et al. (2003), report on a case study of an adult male in Libya at 7800 years before present that may have used his teeth to prepare basket fibers.

7.3. ISOTOPIC ELEMENTS AND OTHER ANALYSES

Isotope and trace element analyses are relatively new fields of study in bioarchaeology. They initially started around 25 years ago, but isotope analyses have become popular in the last five years, whereas trace element analyses have become less frequent. Initially, trace elements (which are small quantities of certain minerals in the skeleton) were thought to be useful in reconstructing dietary differences, such as strontium levels in relation to tuber

consumption since tubers have high levels of strontium and meats have low levels of strontium. As well, marine foods contain strontium in greater percentages than terrestrial meats. Additionally, barium studies were initiated to look at shifts in diet with regard to the amount of meat consumed; carnivores have low barium to calcium ratios, herbivores have slightly higher ratios of barium to calcium, and plants have the most barium compared to calcium. However, whether these levels actually retain their values after death has been questioned. Trace element analyses, which includes as mentioned looking at strontium, barium, and calcium, as well as some other minerals, have fallen out of favor compared to isotope analyses because of the diagenetic changes (changes that occur to the elements from sediments) to trace elements that cloud dietary reconstructions (Safront et al., 1998). For example, analyses of strontium to calcium levels to reconstruct the amount of marine foods compared to terrestrial foods consumed have not been successful (Burton and Price, 1999).

Isotopic analyses, on the other hand, have become very popular in the last several years as mentioned above. The studies examine the composition of bone to reconstruct diet and sometimes migration patterns. Diet can be reconstructed using isotopic analyses and comparisons between sexes, ages, and weaning patterns can be used to reconstruct cultural intricacies. Isotopes are chemical elements that share the same number of protons and electrons, but vary in the number of neutrons; this variation leads to differences in elemental weight. Most elements exist in at least two forms, and the isotopes that bioarchaeologists concentrate on are stable isotopes rather than radioactive ones. Stable isotopes do not change through time and, as such, deterioration after death is not problematic. Radioactive isotopes, which are used for dating methods, change at regular temporal periods and as a result, can be used to date sites. The data to examine diet comes straight for bone samples and it appears that the consumption of different foods is reflected in the ratios of bone composition; thus, you truly are what you eat. The two isotopes that are most commonly examined are carbon (C-12 to C-13 ratio) and nitrogen (N-14 to N-15 ratio).

Carbon isotopes are used to reconstruct the consumption of a variety of plants. Plants can be classified into two categories based on the way in which they metabolize carbon dioxide (CO₂) during photosynthesis. C-12 isotopes produce three carbons after synthesizing carbon dioxide, which is why these plants are known as C3 plants. C3 plants are often non-domesticated plants (Larsen, 1997; Ubelaker, 1989). C-13 isotopes produce four carbons after synthesizing carbon dioxide and, thus, are called C4 plants; C4 plants are usually agricultural plants, such as maize, sorghum, and millet (Larsen, 1997; Ubelaker, 1989). C4 can also be found in marine foods, which can sometimes complicate the picture (Ubelaker, 1989). One of the early findings reviewed by Ubelaker (1989) is the finding that a dramatic rise in consumption of C4 plants (or the increase in C-13 compared to C-12) occurred at about 500 AD in the north-central parts of North America. Within only 500 years, the consumption of C-13 (or C4 plants) accounted for about 70% of the diet (or at least vegetation consumed). This suggests a quick adoption of agriculture and an abandonment of gathering. A recent study by Kellner and Schoeninger (2007) looked at carbon isotopes and divided them into C-13 collagen and C-13 apatite, which when used in a ratio can help reconstruct meat, marine foods, and plant diet. It appears that the ratio of these different forms of C-13 has been shown to differ in experimental data on animals, which is based on what these animals consumed. When taking a look at the ratio of humans, the animals they consumed will be depicted in their bone C-13 collagen to apatite ratios. The authors found that in their experimental study the ratios of C-13 isotope variants matched up with expected diets dependent of

archaeological and zooarchaeological (fauna and flora) evidence; for example, the South African cape population had diets with pure C-13 diets that were indicative of marine resources. This study is of interest due to its concentration of carbon isotopes and the specificity of dietary reconstruction that they propose is possible. Many of the other recent studies use multiple indicators of diet to reconstruct the past or focus on nitrogen isotopes.

Nitrogen comes in two isotopes (N-14 and N-15) that are of interest to bioarchaeologists. The ratio of these isotopes can be used to reconstruct the amount of marine foods were utilized by prehistoric populations. Additionally, N-15 also has been linked to legumes, such as beans, and the amount of N-15 in diets increased in the New World with the adoption of agriculture (Ubelaker, 1989). Interestingly, after European contact, the ratio of N-15 to N-14 seems to drop to preagricultural levels when examining coprolite data, which may suggest that diet changed in relation to legume consumption, or rather that marine foods were consumed less since N-15 is also found in marine foods in higher rates than in terrestrial meats. Another possibility is that there are confounds that have not been ironed out; Ubelaker (1989) points out that environmental contaminants can affect isotope levels. Some isotopes, such as oxygen, are even used to reconstruct migration patterns since the air and water of various places hold different types of oxygen isotopes at different levels, and testing the enamel (since teeth do not remodel) can indicate whether people were born at the location they were from or migrated to the location (e.g., Prowse et al., 2007). Nonetheless, anthropologists using isotope ratios that include carbon and nitrogen isotopes have been effective in reconstructing diet; the use of multiple diet markers helps to eliminate some of the complications mentioned above.

Sometimes, access to resources does not necessarily correspond with the use of those resources; for example, L  sch and colleagues (2006) examined stable isotopes of the Neolithic Fertile Crescent region in Anatolia. They found that, although there were domesticated animal bones at the site, isotope ratios indicated a lack of use of the animal resources. It seems that these animals were domesticated and fed, which is supported by the type of animal bones found and their isotope levels (that were high in C-13). Even after the transition from hunting-gathering to agriculture and livestock took place, consumption of livestock had not impacted the diet to a great extent. The outcome of this is that individuals had increased the non-meat component of their diet prior to increasing the meat portion of their diet with livestock. It may be that the use of livestock for dairy or other purposes seemed to outweigh the advantages of eating the livestock.

Another example of resource availability and consumption contradictions comes from Greece. A study of Neolithic Grecian skeletal remains has revealed the low use of marine resources even when the resources are nearby (Papathanasiou, 2003). In a sample of 101 individuals, Papathanasiou examined nitrogen and carbon isotopes of inland and coastal populations dating around 6800 BC. This sample has evidence of cribra orbitalia and porotic hyperostosis, which can be linked to anemia either due to a dietary lack of iron, anemia as a result of parasites, or hereditary anemia (that has been documented in Grecian samples prior). The results showed low levels of variation between populations and individuals, which suggests a homogeneity of diet and culture related to diet. Furthermore, the overall N-15 values were low, suggesting that marine resources were not utilized greatly. Wheat, barley, and legumes seemed to be the main caloric content of the diet. Coastal populations had slightly greater ratios of N-15 to indicate that they used marine resources more than inland populations. The high reliance of agricultural foods may be due to reliability of food

availability, storage ability of foods, and conflicts of working fields can have with fishing activities. Additionally, domesticated animals may have augmented the prestige of individuals. Bourbou and Richards (2007) also examined a population from Greece; their sample occupied the Middle Byzantine (11th Century AD) and included 59 individuals. They found that N-15 levels were high, which suggested marine resources were utilized during this period. Literature on the Greek populations during this temporal period supports the use of marine protein.

Prowse and colleagues (2005) looked at a sample of Imperial (1st and 3rd Century AD) Roman skeletons from Isola Sacra (Rome, Italy) to reconstruct dietary shifts related to aging and sex differences. From 105 skeletons, the authors found that carbon and nitrogen isotope levels indicated a diet higher in marine resources in males compared to females, which suggests that females were considered lower status. Resources from writings and archaeological information support this gender bias. Interestingly, old individuals consumed high-quality foods as represented by N-15 levels and low levels of C-13. It may be that the elderly came from higher social classes, which helped them live beyond 45 years of age, or that the elderly gained social status due to a cultural mode that reveres the elderly. Conversely, sub-adults had diets that were lowest in marine resources and highest in lower-quality grains, which corresponds to enamel hypoplasia and cribra orbitalia found in these individuals, and suggests that either those young individuals who died may have been of lower status or that in general children were nutritionally disadvantaged.

Data from the United Kingdom has also highlighted several interesting cultural tendencies. For example, Müldner and Richards (2007a) examined a skeletal sample of 155 from a York cemetery that dates between 13th and 16th Century AD. They found a great degree of variation in the diets of individuals based on carbon and nitrogen ratios. They also found a lack of status differences in marine and dairy consumption as indicated by N-15 levels. The authors suggest that the low cost of herring and dairy may have aided in the nutritional value of diets of the poor. They did, however, find a slight sex difference in burials that were not close to the church. The proximity of the burial to the church is an indicator of status, clerical individuals were often buried right by the church as were individuals who had supported the church through donations. In the burials closest to the church, no sex differences in diet were found, but in distant burial females seemed to have lower marine food consumption than males. This may in part be due to the female migration from farmlands after the Black Plague (AD 1349) sometimes when the males died and females could not take care of the farms. This migration is documented and females looking for work in more urban settings could still have the dietary indicators of rural lifestyle: low N-15 and high C-13 levels. Müldner and Richards (2007b) expanded their research of York to include a dietary reconstruction of the last 1500 years with a sample of over 300 individuals. The most significant findings was that, although marine resources were scarcely used, sporadically throughout time marine resources were reintroduced to the British diet and increased in importance in the 11th Century AD, which could be linked to imposed fasting by the Church.

Another interesting cultural factor that has been examined with the use of stable isotopes is the differences in weaning patterns. Experimental data has provided evidence that nitrogen levels are more effective than carbon levels, although both can be used, to determine age at weaning (Fuller et al., 2006a). Interestingly, early-on enamel hypoplasia was thought to be a good indicator of weaning age, but this assumes that weaning was always stressful. Nitrogen isotope ratios and nitrogen/carbon ratios provide a better way to determine weaning without

assuming stress. The basic theory behind correlating nitrogen and nitrogen/carbon ratios with weaning relates to food chain information; carnivores and those who do not consume vegetation have high levels of N-15, whereas herbivores tend to have decreased levels of N-15. Thus, when an infant is born and not consuming plants, the infant will initially have the mother's nitrogen level and then this N-15 level increases upon the onset of breastfeeding. Mothers of breastfed babies are lower in N-15 than their infants and N-15 decreases with age as a gradual process. Thus, the fluctuation of nitrogen is that at birth the N-15 of the infant is like that of the mother and then it increases due to the contents of breast milk and the lack of other dietary components (Fuller et al., 2006a). Once weaning has begun, additional food sources and less breast milk leads to a decrease in N-15. Nitrogen-15 levels can be measured through skeletal remains and by examining enamel; when measures are made using the subadult skeletons the data may be skewed by the necessity of examining individuals who did not live past weaning age along with those who lived shortly after weaning age. Since tooth enamel does not remodel and dental formation and eruption patterns are tightly controlled by genetics, one can examine adults to determine weaning patterns and, thus, the data is not skewed by those individuals who died early in life (Prowse et al., 2008).

Perhaps the most interesting finding of nitrogen isotope ratios and nitrogen-carbon isotope ratios is the cross-cultural continuity. In samples from Imperial Rome (Prowse et al., 2008), Middle Byzantine Crete (Bourbou and Richards, 2007), Medieval Nubia (Turner et al., 2007), Late/Sub-Roman Britain (Fuller et al., 2006b), Iron Age Britain (Jay et al., 2008), mid-Holocene South African hunter-gatherers (Clayton et al., 2006), and Roman period Egypt (Dupras and Tocheri, 2007), it appears weaning started at around 2 years of age and was completed somewhere between 2.5 and 4 years of age, depending on how gradual the weaning process occurs in various locations. Currently in industrial nations, weaning usually occurs within the first year of infancy. The extended breast feeding of prehistoric and protohistoric populations might have meant that birth intervals throughout prehistory were more in line with our great ape cousins: chimpanzees and gorillas; it appears that 3 to 4 year birth intervals may have been the norm. Breastfeeding commonly suppresses ovulation when dietary calories and body fat content are low. It also suggests that, regardless of environmental stresses, the biological ability to breastfeed longer may not be available and the children at these ages are likely to require more calories and nutrition than available through breast milk alone. Still, more ancient examples of breastfeeding practices need to be conducted and New World data is absent to complete the argument for universality of weaning practices.

7.4. CRANIAL INDICATORS OF DIET

Anthropologists often either identify craniofacial traits with heredity or environment, but recently anthropologists have noted that these traits are influenced by both genetics and the environment. Part of the dilemma has arisen from earlier studies by Boas who stated that differences in overall skull shape were environmental rather than genetic, while more recent studies have found it difficult to replicate Boas's finding on skull shape (e.g., Gonzalez-Jose et al., 2005). Anthropologists have been torn between being genetic adaptationists or functional adaptationists, but the truth likely lies in between the two extremes. Determining

which traits are more influenced by what we eat and which are more influenced by who we are related to has been difficult; nonetheless, there are anthropologists who are taking on that task (e.g., Gonzalez-Jose et al. 2004; Sparks and Jantz, 2002). Experimental data has proven that different foods will have effects on craniofacial morphology; Larsen (1997) mentions experiments on lab animals that are given hard and soft foods. The soft food animals ended up with smaller and less robust craniofacial dimensions than the hard food animals. Additional evidence of the plasticity of the skull comes from in vivo bone strain measurements (Bouvier, 1985); basically, since the skull is made of bone, strains that threaten to break the bone should lead to remodeling of bone and, therefore, changes in craniofacial shape. Environmental influence on skull morphology has been associated with mechanical loads (e.g., Heathcote and colleagues, 1996; Steen and Lane, 1998) that are unrelated to food consumption and those studies that examine masticatory loads in relation to diet (e.g., Gonzalez-Jose et al., 2005a; Pinhasi et al., 2008; Sardi et al., 2006; Spencer and Ungar, 2000).

Non-dietary examinations mentioned looked at muscle marker data similar to the post-cranial muscle marker data mentioned in the earlier chapter on reconstructing activity patterns. Heathcote and colleagues (1996), for example, examined posterior cranial muscle markers of male Mariana Islanders with a sample size of about 100 that dated between 1000 AD and 1521 AD in regards to muscles utilized for carrying and constructing megalithic structures. They found that the extreme development of the posterior muscle markers could be explained through megalithic construction, but that more comparative data are needed. Steen and Lane (1998) looked at two populations of Alaskan Eskimo and their muscle marker differences. The two Eskimo populations consisted each of over 100 individuals with males and females present of similar temporal periods and age ranges. Ethnographic data has suggested that the females of one population (Nunivak Island) did not chew hides routinely whereas the females of the Golovin Bay population did chew hides routinely. The examination of 14 cranial and mandibular muscle markers revealed 3 out of 4 findings between the females of the two populations were significantly different; the females of the hide chewing population (Golovin Bay) had higher muscle markers than the non-hide chewing females. However, for the *occipitalis* the same differences was found in males. Other differences between males in the two populations were linked to stresses of the nuchal muscles that involved load-carrying using tumplines. Interestingly, there were sex differences in both populations and every significant sex difference favored male robusticity in comparison to female robusticity, which suggests that there may be body size or biological sex confounds.

Dietary studies are less likely to concentrate on muscle markers and more likely to look at metric dimensions. Spencer and Ungar (2000) looked at craniofacial changes in humans as a response to anterior loading (i.e., loading pressures on the incisors). They sampled data from proto-historic Aleutian Islands (N = 25), late Woodland Amerinds from Illinois (N = 24), and proto-historic Arikara Amerinds from South Dakota (N = 19). The Aleutian Islanders were reported to have almost exclusively animal subsistence that was mainly based on marine foods; they are of interest because of their tough diet that consisted of tough dried meat and rarely cooked foods (which is because of the lack of fuel resources in their environment). Thus, the stresses placed on the anterior teeth were likely very high. The Illinois sample likely ate plants and some meats; they are known to have consumed nuts, tubers, and small game animals. They likely had low levels of stress placed on their anterior teeth and should have

much lower levels of craniofacial robusticity. Finally, the Arikara of Dakota should have robusticity levels in between the other two populations, since they consumed bison and cooked their meat. Spencer and Ungar collected data on 28 traits that were taken as three-dimensional coordinates and found that twenty traits (such as condylar breadth, mandibular depth, and bizygomatic breadth) displayed differences between the three groups. It appears that changes in muscle positions provide a mechanical advantage when populations are faced with anterior stresses. Thus, dietary differences do lead to differences in craniofacial morphology, especially as they relate to muscle positions.

Gonzalez-Jose and colleagues (2005a) found that, by examining 30 measurements (such as optic length, facial width, and alveolar length) of the skull and jaw in 569 skulls that belonged to 18 South American Amerind populations, they could determine which craniofacial traits were most likely influenced by diet and which were influenced by genetics. The sample consisted of hunter-gatherers and farming populations; the hunter-gatherers were expected to have greater values in metric measurements than the farmers since the processing of food in farmers would have led to less stress on the masticatory system (the part of the skull involved with chewing, such as jaws and teeth). They found that not all traits were distinct between the hunter-gatherers and the farmers, especially volumetric and morphometric indices (such as overall cranial shape), which were similar in the two groups. The traits that were most affected by diet seemed to be in the alveolar (tooth sockets area) region and related directly to the masticatory system. In other words, not all data is as good at detecting dietary differences and the data that may seem to be similar in both subsistence groups tends to be related to genetic influences. This also suggests that bone remodeling takes place at localized levels in the body as opposed to throughout the body regardless of where the stress is actually placed.

Sardi and coworkers (2006) found some similar and different results when looking at Argentinean remains. Using a sample of hunter-gatherers ($N = 66$), agriculturalists ($N = 58$), and Portuguese urbanites ($N = 202$) they examined metric, volumetric, and morphometric traits of the face and skull. Their results indicated that the agricultural group had smaller components for most traits with the masticatory and back of the skull having the greatest decrease in size compared to the other two groups. This difference may relate to dietary mechanic stresses, decreases in protein consumption, or shifts in hormonal levels based on diet.

In the Levant, Pinhasi and colleagues (2008) also noted a decrease in the masticatory traits upon the adoption of agriculture. They took data on 242 individuals from five archaeological periods (ranging from 12000 to 7000 years ago) to examine the effects of early agricultural adoption on dentition and craniofacial morphology. They found a decrease in tooth size, but no decrease in the overall dimensions of the mandible. Rather only two metrics on the mandible changed (anterior symphyseal height, which is the height at the middle part of the jaw that are two halves prior to fusion, and ramus breadth, which is how broad the upper part of the mandible is that connects up to the skull). Even with these scarce results, the authors suggest that the changes visible are due to masticatory functions, but whether the changes are based on natural selection and, thus, genetic in nature or environmental adaptation based on remodeling is difficult to say since tooth size does not change throughout one's life and is known to be tightly controlled by genes. Thus, it appears that craniofacial morphology has some plasticity, but that genetics also accounts for some of the

morphological change. In the next chapter, craniometrics in relation to biological relatedness will be addressed.

7.5. CHAPTER SUMMARY

Anthropologists have used a variety of techniques to reconstruct diet and use of teeth as tools. Coprolite evidence has given us clues to the degree of small animal game consumed by Amerindians of the past whereas malocclusion has increased with the softer foods of agriculture compared to hunter-gatherers. Other evidence, such as occlusal wear (i.e., abrasion – food that wears down teeth, and attrition – tooth on tooth wear) has given us clues to how agriculture has changed dental health, such as with less attrition there is an increase in caries. Additionally, isotopic analyses have allowed anthropologists a way to test bones and teeth for dietary variation that includes the amount of marine versus terrestrial foods consumed and the amount of gathered versus cultivated plants consumed. Isotopes also give us universal clues to weaning ages and the cross-cultural effects of weaning without the assumption of stress at time of weaning. Finally, the plasticity of the masticatory system has provided anthropologists with clues to the use of teeth as tools, but also allowed for the determination of which parts of the skull are determined through genetics and therefore good for biological relationships and which parts of the skull are most influenced by diet and other environmental factors.

Key Terms

Abrasion
Attrition
Adaptation
Alveolar
Caries
Coprolites
Craniofacial morphology
Dental microwear
Diagenetic
Isotope
Malocclusion
Mandibular symphysis
Masticatory system
Occlusal wear
Scanning electron microscope
Trace elements
Weaning

Chapter Questions

- 1) How are coprolites used to reconstruct diet?
- 2) Which isotopes are used to determine marine versus terrestrial food shifts?

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- 3) What evidence for weaning has been found with carbon and nitrogen isotopes?
 - 4) Why are trace elements not often used in dietary reconstructions?
 - 5) Which parts of the skull are most useful for dietary reconstruction?
 - 6) How do bone and teeth differ in regards to isotopic analyses and craniofacial studies?

Chapter 8

BIOLOGICAL RELATIONSHIPS: WHO IS RELATED TO WHOM

8.1. INTRODUCTION TO BIOLOGICAL RELATIONSHIPS AND THEIR MEANINGS

Anthropologists use skeletal, dental, and DNA evidence to retrace biological relatedness. Often termed as biological distance, biological relatedness is the measure of genetic affinity between populations. The assumption in bioarchaeology is that individuals who are most closely related will display the most similarities (Ubelaker, 1989). Larsen (1997), Ubelaker (1989), and other texts have pointed out that anthropologists have traditionally used skeletal (and more specifically, craniometric) traits to reconstruct family ties; however, dental morphology and even more recently ancient DNA (also known as aDNA) has been useful in reconstructing past relationships. Advances in statistical methods have allowed anthropologists to utilize large sample sizes and multiple traits to determine relatedness as opposed to just looking at single traits. It is important to consider the aggregation principle, which basically states that the more measures used, the more likely the true effect will be measured because the assumption is that the error rates will be random and cancel one another out (Weiss, 2003a). Nonetheless, the tracing of biological relatedness effectively depends on the adequacy of the sample (because any one individual could just be an outlier in the distribution of the traits in the population) and the degree to which the traits are determined by genetics. As seen in earlier chapters, skeletal morphology is influenced by the environment, but some parts of the skeleton are under tighter genetic control than others. Dental morphology, for example, seems to be under tight genetic control (Larsen, 1997), but some environmental impacts may still alter tooth morphology. Craniofacial morphology seems to be controlled by genes more than post-cranial morphology. However, anthropologists who have examined cranial morphology to reconstruct activities and the influence of subsistence, such as Heathcote and colleagues' (1996) work on the Mariana Islands and construction of megaliths, Sardi and colleagues' (2006) work on dietary transitions and craniofacial morphology, and Gonzalez-Jose and co-researchers' (2005a) work on Amerinds and subsistence patterns, have argued for the plasticity of the cranium in response to environmental pressures. Studies done on both human and non-human primates

support the elasticity of craniofacial and mandibular skeletal morphology (Bouvier, 1985; Dechow et al., 1993; Wang and Dechow, 2006; Weijs and Hillen, 1986). With these confounds, one must still examine the best indicators possible to retrace relatedness and those do appear to be in the crania, the dentition, and the DNA.

8.2. DENTAL AND CRANIAL TRAITS

Dental Morphology

Dental morphology is a popular tool to examine biological relatedness. Anthropologists have contended that much of dental morphology is controlled by genetics and that permanent teeth morphology can be utilized in reconstructing past biological relationships (e.g., Irish, 2005, 2006; Irish and Konigsberg, 2007). Traits that are commonly used are the presence of shovel-shaped incisors (Figure 8.1), cusp patterns on molars and premolars, and dental size. The description of these traits can be found in Buikstra and Ubelaker (1994) *Standards for Data Collection of Human Remains*. Table 8.1 describes some of the dental traits used by anthropologists to reconstruct biological relatedness. Irish (2005, 2006), for example, utilized dental markers to reconstruct the origins of Egyptian pharaohs and determined genetic continuity for Egyptian populations until the Christians arrived from Rome through the use of discrete dental morphology.



Figure 8.1. Shovel-shaped incisor. Photo taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.

Table 8.1. Dental traits used to retrace biological relatedness

Trait	Definition
Shoveling Incisors	Raised ridges on the lingual surface of the tooth.
Carabelli's Trait	Extra cusp on an upper molar that occurs on the lingual surface on the mesiolingual cusp.
Winging	Rotation of the upper central incisors that give the two teeth a v-shaped orientation.
Hypocone	Extra cusp present on the distolingual area of an upper molar.
Peg Shaped Incisors	Reduction of incisor size and a lack of normal crown morphology.

Another study that looked at dental traits included a large comparative sample to determine population origins of Jebel Moya (a Southern Sudan site) dated from 5000 BC to 100 BC. Irish and Konigsberg (2007) compared dental data from the Jebel Moya to data from Sub-Saharan and North African sites and utilized three dozen nonmetric traits. The authors found that the population of Jebel Moya had incredible heterogeneity of traits and both Sub-Saharan and North African traits were accounted for in the archaeological site. This dental data confers with earlier craniometric data employed on the sample site with the same comparative data sets. The results of heterogeneity suggest that Jebel Moya was a site many passed through for travel and trade, which made the population diverse – a diversity found in the skeleton.

The question about the origin of the earliest Southwestern US agriculturalists has also been addressed through dental morphology (LeBlanc et al., 2008). Anthropologists have been attempting to determine whether the onset of agriculture in the Southwestern United States by the Western and Eastern Basketmaker cultural groups are the result of Central Mexican migration into the northern area that is now the US or due to a single origin in the US and an adoption of agriculture by the Basketmakers who later split into two groups that once shared a common origin. LeBlanc and colleagues found that using discrete dental markers on permanent teeth revealed that the Western Basketmakers did share similarities with Central Mexican populations and were distinct from the Eastern Basketmakers, who were not similar to any group tested. This suggests that the adoption of agriculture and basket making may have been due to contact rather than a single origin for the Basketmakers and then the dispersion of the cultural artifacts and subsistence pattern. It is interesting that cultures may be similar, but biological relatedness should not be assumed.

In Nubia, biological continuity has also been raised as an issue in two groups that ranged from 3100–2500 BC to 2000–1500 BC due to the different subsistence patterns utilized and the increase in stratification from egalitarian societies. Johnson and colleagues (1995) found that non-metric dental traits analyzed for the two periods provided evidence that the two groups were biologically continuous, although the culture had changed rapidly. Interestingly, they point out that premolars and molars are most useful in determining relatedness, since anterior teeth (incisors and canines) are more often missing or broken. Furthermore, they examined asymmetry, but found that results remained the same whether they used right, left, or a combination of what was available. Asymmetry, the authors thought, may be important due to evidence that fluctuating asymmetry in dental morphology is due to environmental pressures, especially in the prenatal and early stages of life. Their result of biological

continuity is supported through other studies that have examined craniometrics traits in the same populations (e.g., Prowse and Lovell, 1995).

In a rare example employing deciduous dentition, Kitagawa (2000) found support for a distinct origin for the prehistoric Jomon of Japan. Kitagawa (2000) examined seventeen discrete traits (which refers to traits that are either present or absent rather than measured) on deciduous teeth in Japanese samples that span 4000 years to determine whether earlier populations of Japanese, such as the Jomon who occupied Japan from 4000 to 2300 years BP, are related to the present day Ainu and modern mainland Japanese. Kitagawa examined 427 teeth from archaeological samples and 924 teeth from clinical samples to look at whether traits on the deciduous teeth, such as shovel-shaped incisors and molar cusp patterns, would provide the support for the hypothesis that the Jomon are distinct from modern Japanese. Previous research on permanent dentition has found that the teeth of Asian populations can be divided into two clusters: Sinodont (who are the Northeast Asians and Native Americans) and Sundadont (who are the Southeast Asians, Polynesians, and Micronesians). The earlier research placed the pre-historic Jomon in the Sundadont group while the modern Japanese were grouped with the Sinodonts. The evidence suggests that there are different origins for the two populations. Deciduous teeth, interestingly, provide the same evidence, but with different traits. This study is of interest due to the use of deciduous teeth and the ability to provide further support for an independent origin of the modern Japanese compared to the prehistoric populations; likely, they migrated from further north downward whereas the Jomon represent a more southern origin.

Metric and Discrete Cranial Traits

Similar to dental morphology, cranial morphology has been used to reconstruct biological relationships. Craniometry and non-metric cranial traits have become two of the most popular ways to reconstruct biological relationships, especially since the use of aDNA is still quite expensive and issues of contamination or lack of significant DNA material are still issues concerning the field of aDNA studies. Anthropologists have repeatedly tried to determine which cranial traits are genetic in origin and lack environmental plasticity. For example, Varela and Cocilovo (2007) examined a variety of craniometric traits that are used in biological relatedness studies, such as cheek height, orbital breadth, orbital-alveolar height, and cranial length, in a sample of 237 crania from Chile to determine whether crania were linked to culturally diverse groups or whether they fit the genetic model of stability in this region where gene flow is doubted. Some nonmetric traits include wormian bones (Figure 8.2), supraorbital notches (variation of number of notches or foramen above the eye), and metopic suture (suture that runs across the frontal bone that usually disappears by adolescence; Figure 8.3) presence. The authors found that the likelihood that these cranial traits are genetically controlled is very high and they suggest that 83% of the variance between traits is due to genetics and only 17% is due to environment. Thus, they are aware of an environmental impact, but think that this impact is low. Other studies have tested their cranial data in comparison with mtDNA and nuclear DNA evidence and found that both types of evidence provide the same biological relationship trees (e.g., Perez et al., 2007). Nonetheless, anthropologists have shown evidence that cultural cranial modification can change both cranial and facial morphology; in locations where the cultural practice of deformation was prevalent in high frequencies this causes a real dilemma when trying to utilize the skull for retracing biodistances (Sutter and Mertz, 2004).



Figure 8.2. An adult male skull with wormian bones. Taken from E. Barclay-Smith: A Rare Condition of Wormian Ossifications. *J Anat Physiol.* 43(Pt 3), 277–278 (1909).



Figure 8.3. An adult male skull with a metopic suture. Photo taken by Elizabeth Weiss at San Jose State University's Anthropology Lab.

Interestingly, Sutter and Mertz found that the use of nonmetric traits of the crania led to different conclusions compared to metric traits when examining the Azapa Valley in Chile. They found that using 37 nonmetric cranial traits (which were boiled down to eight traits) in a sample of over 400 individuals over a span of 5000 years revealed biological continuity in Chile, whereas earlier studies employing metric traits came to the conclusion that gene flow changed the population in Chile. The authors did find that breeding isolation occurred that separated coastal and inland populations, but that these reflected genetic drift. Temporal changes in cranial morphology were absent.

The Americas are a hot bed for cranial studies to determine biodistance as you may have noticed above. Other studies include the examination of the peopling of the Americas, such as Gonzalez-Jose and co-workers' (2005b) research on over 500 skulls that suggest recent migrations from Asia and the circumarctic populations may have been preceded by earlier migrations. In North America, craniometric measures have also been used to determine cultural mating practices rather than origins. The prehistoric Tewa who occupied New Mexico, Arizona, Colorado, and Utah were examined by Schillaci and Stojanowski, who looked at skulls ($N = 128$) from sites dating between 1350 and 1550 AD to determine whether the populations were matrilocal (cultural custom in which a married couple lives with or near the wife's parents) or patrilocal (cultural custom in which a married couple lives with or near the husband's parents). Patrilocal cultures are more common than matrilocal cultures. The authors decided to concentrate on facial bones, since some anthropologists suggest that they are less affected by cultural skull modification than cranial bones; they discovered the Tewa were matrilocal (the facial traits could be traced through the females) and that endogamy (or inbreeding) appeared to be common. Yet, heterogeneity in some sites suggests a variation of the degree of endogamy and possible gene flow into populations.

In South America, Varela and colleagues (2008) examined the relationship of Argentinean, Bolivian, and Chilean prehistoric populations through the use of 1586 crania from both sexes. Their craniometric data suggests that the Bolivian population may have given rise to both the Chilean and Argentinean samples since both groups have more similar morphologies to the Bolivian sample than to each other. An additional South American study looked at whether multiple migrations helped to explain the vast diversity in craniometrics; multiple migrations seem possible, or other explanations, such as older origins than originally thought, could help to explain the diversity seen in South American skulls (Sardi et al., 2005). Perez and colleagues (2007) also suggest that strong selective forces and genetic drift could result in breeding populations that are different from one another in South America. Fabra and colleagues (2007) examined South American skulls; they were interested in who inhabited the central Argentinean landscape and whether those individuals also contributed to populating more southern parts of Argentina. Their craniometric results showed evidence that the migrations came in waves from more northeastern locations (rather than Andean regions) which helps explain why Andeans appear so different compared to Argentineans both in skeletal and living morphology. Additionally, through the use of the 38 skulls in comparison to other samples, the authors contend that the wave did not stop in central Argentina, but rather the traits are visible in the southern tip of Argentina. It appears that gene flow in waves from the north-east affected all of central and southern Argentina and the possible migrations may have run along the Atlantic coast or along rivers, both of which would have provided a fast means of migration and plentiful resources.

Other areas of the world have also been of interest to anthropologists who are trying to reconstruct past population dynamics. For example, prehistoric Polynesians have been studied through craniometrics and discrete cranial traits to determine whether distinctions between Southeastern and Northwestern Islanders in the Marquesas Islands are culturally bound or based on biological differences (Stefan and Chapman, 2003). Research on 28 discrete traits and 49 metric traits on over 200 skulls dating at around 1110 AD reveal that the two sets of islanders are distinct and were likely isolated breeding populations. An interesting study in a very different climate came from Iceland. Hallgrímsson and coworkers (2004) examined the Icelandic literature and found mention of Irish immigrants to early Iceland. If the Irish cohort was large, then this should be visible in cranial traits. They examined crania of about 400 skulls from the National Museum of Iceland that belonged to pre-Christian immigrants into Iceland. They also examined Viking and Iron Age skulls from Norway that were curated at the Anatomical Institute at the University of Oslo and looked at 101 skeletons from an early medieval Irish population. The Icelandic skulls were most morphologically similar to the Viking Norway populations, which suggested that the mention of the Irish immigrants in the literature may have been exaggerated. Interestingly, the skulls are homogenous and show continuity in Iceland through time, which is likely a result of the isolation Icelanders experience.

8.3. ADNA STUDIES

Instead of examining skeletal remains and attempting to determine which traits are genetic and which are influenced by environment, some anthropologists have started extracting DNA from skeletal remains (e.g., Adachi et al., 2009; Cabana et al., 2008; Casas et al., 2006; Shook and Smith, 2008). The oldest DNA extracted so far is about 130000 years old, but the quality of DNA differs drastically and age of the DNA is not the main cause of the variation in quality. The site the remains are found in is the main determining factor of whether DNA can be successfully extracted and tested; Kennewick Man (a 9000-year-old skeleton from Washington state that was said to have Caucasoid features) made this painfully clear. Paleoamerican DNA studies have fallen short many times, which is especially agonizing considering the importance of determining their difference from modern Native Americans to prevent the bones from being reburied. Nonetheless, aDNA studies (the “a” stands for ancient) have been increasing in popularity and are used to answer social structure questions, marriage patterns, burial customs, migration patterns, and sex of subadult individuals (Kaestle and Horsburgh, 2002). Many of the most recent studies concern tracing population movement and ancestor-descendent relationships (e.g., Moraga et al., 2005; Ricaut et al., 2006).

Anthropologists started aDNA studies in the mid-1980s, but these studies were most often focused on perfecting techniques and ridding samples of contamination (Kaestle and Horsburgh, 2002). Recently, polymerase chain reaction (PCR) techniques have revolutionized DNA studies by allowing less complete DNA to be tested and amplifying short fragments to allow for replication studies and determination of reproducible results (Kaestle and Horsburgh, 2002). Perhaps some of the most famous aDNA studies are those that involve Neanderthal DNA; these studies have strengthened the argument that Neanderthals were not

H. sapiens but rather shared the last common ancestor with us at around 600000 years ago. Even with spectacular successes at times, aDNA studies are still submersed with difficulties, expensive, and destructive (Kaestle and Horsburgh, 2002). Roberts and Ingham (2008), for example, point out that about 90% of aDNA studies published in peer-reviewed journals fail to mention controls to remove contamination, such as cleansing the samples with bleach or UV radiation. They also state that 85% of studies fail to validate results independently and, since science is based on the ability to reproduce results, the lack of validation is problematic. Finally, Roberts and Ingham (2008) argue for clearer descriptions of methods utilized in studies. Additional difficulties arise due to small sample sizes and the high frequency of case studies (e.g., Mooder et al., 2006; Ricaut et al., 2006)

With all the negatives of aDNA, it is still interesting to examine recent research that has found aDNA useful in answering questions about prehistory. Adachi and colleagues (2009) utilized mtDNA of Jomon prehistoric Japanese remains and searched for Native American origins. Mitochondrial DNA from 16 skeletons dating around 3800 years ago was compared to mtDNA from modern populations and the authors found that the Jomon genotype was shared very scarcely with Siberians, Koreans, and Japanese. Additionally, Native Americans may share some Jomon genotype (suggesting that Native Americans came from Asia), but interestingly the Ainu (who are considered modern day descendent of the Jomon) are just as distinct from the Jomon as other tested populations.

In an early study by Shinoda and Kunisada (1994) a 2000-year-old site was uncovered in southwestern Japan. Mitochondrial DNA (mtDNA), which is only passed through the maternal line and thus can be used to trace biological relationships and time divergences of cultures and peoples, was extracted from 55 individuals (who were grouped into 16 different types). The authors found individuals who were closely related were buried close to one another, which supports that social differentiation and family structure had already begun several thousand years ago in Japan. These results are in accordance with archaeological reconstructions of prehistoric Japan.

In another cemetery located in Upper Canada, Dudar and colleagues (2003) utilized recovered and amplified aDNA from a documented 19th Century cemetery. They found that the replacement of mtDNA clusters every two generations may suggest patrilineal kinship structures; the use of aDNA from the Y-chromosome also supports this cultural reconstruction. The authors emphasize the need for multiple techniques for retracing kinship structure, since illegitimacy and adoption may lead to incorrect information, but the aDNA provides biological evidence that cannot be altered by culture.

In examining aDNA from Northeastern US and Canada, Shook and Smith (2008) tried to untangle the population history from 3000 years ago to 800 years ago. They analyzed mtDNA of 59 individuals from six prehistoric sites to determine biological relationships and demographic changes. Their results suggest that some modern day descendents can trace their biological relatedness back to 3000 years, but that much information has been lost due to a population crash after European contact, genetic drift, and gene flow from the Algonquian-speaking Native Americans.

In Europe, the Iberian population has been linked to both Africa and the European continent. Casas and coworkers (2006) tested whether 12th to 13th Century remains from Medieval Spain were genetically more similar to Northern Africans or Europeans. They found that the African (and, likely, Islamic) influence was high by looking at haplotypes of aDNA, but that the modern population is more similar to the rest of Spain rather than to the

medieval Spaniards occupying the area. Gene flow, they argue, may have caused this difference between modern and medieval al-Andalus Spaniards.

In the future, aDNA studies will likely increase in popularity and in quality. Calls for replication studies and multiple methods of answering hypotheses have been heeded by some. Increased sample sizes may also reveal more definitive answers regarding relationships, since the larger samples will likely contain greater degrees of variation that better represent past populations.

8.4. CHAPTER SUMMARY

Tracing biological relationships has helped us understand our origins and various cultural practices; the methods used to reconstruct the relationships vary from dental traits, to cranial traits, to aDNA. Both dental and cranial (or craniofacial) traits can be divided into two distinct types: metric and discrete traits. Metric traits are those that can be measured, whereas discrete traits are either present or absent. Sometimes these traits will draw the same family tree while other times the metric and discrete traits are not in accord with one another. Another difficulty in drawing evolutionary family trees occurs when dental traits and cranial traits tell different stories of relationships. These complications are likely due to the interplay between genetics and environment on the traits; traits that are most useful for reconstructing the biological family trees are those that are tightly controlled by genetics and not influenced by the environment. Dentition is thought of as being only influenced through dental wear, but tooth size, cusp-pattern, and shoveling of incisors are all thought to be under tight genetic control. These traits also appear at young ages and do not change with age. In other words, looking at dentition appears to be a good way to understand past relationships. Cranial traits have more plasticity since the craniofacial bones are, indeed, bones and undergo bone remodeling throughout life. Environmental factors that have been linked to changes in craniofacial morphology include artificial cranial deformation and dietary changes; these environmental forces can increase or decrease jaw sizes, change the number of wormian bones, and even change the facial angles. Thus, cranial traits, although used frequently, have been criticized by others as far from ideal tools for reconstructing past relationships. Rather than trying to determine which traits are influenced by the environment and which are not, some anthropologists have started to examine DNA (both nuclear and mtDNA as well as the Y-chromosome). Ancient DNA is difficult to extract and costly, but results have provided us with a new way to sex the youngest individuals; trace evolutionary family trees, such as continuity with Medieval Spaniards and North Africans; establish links between Amerinds of Upper Canada and modern descendents; and disprove the long-held notion that the Ainu of Japan are descendents of the prehistoric Jomon of Japan. More aDNA studies are likely to arise each year, and although the early studies had problems with contamination and standardization, more replication studies are likely to follow and answers to hypotheses will be forthcoming that will either require us to disregard past theories or provide support for those past theories.

Key Terms

aDNA
Biodistance
Carabelli's Cusp
Contamination
Cranioimetry
Cusp Patterns
Discrete Traits
Endogamy
Matrilocal
Metopic Suture
Metric Traits
mtDNA
Patrilocal
PCR
Peg Shaped Incisors
Shovel-Shaped Incisors
Sinodont
Sundadont
Supraorbital Notches
Winging Incisors
Wormian Bones

Chapter Questions

- 1) What types of dental traits have been examined to reconstruct past relationships?
- 2) How do discrete and metric traits differ? Give some examples of each and how they have been used to reconstruct past relationships.
- 3) Why is artificial cranial deformation problematic to reconstructing past relationships and how do anthropologists try to resolve these issues?
- 4) What is the oldest DNA that has been extracted from human bone?
- 5) What are some of the difficulties that have arisen with DNA studies?

Chapter 9

THE FUTURE OF BIOARCHAEOLOGY: WHERE DO WE GO FROM HERE

9.1. INTRODUCTION TO THE FUTURE OF BIOARCHAEOLOGY

Bioarchaeology, although one of the lesser-known fields of physical anthropology, is one of the most researched topics in physical anthropology. Internationally, bioarchaeology, which is an ever-growing dynamic research field, has gained in popularity and we have a renaissance of anthropological studies coming from both Western and Eastern Europe. North and South American anthropologists continue to make significant contributions to the field of bioarchaeology as well.

9.2. NAGPRA AND RELIGION

The future of bioarchaeology is a controversial topic that does not only delve into the intricacies of scientific questions and new theories and methods to test those theories but also involves the legality of studying remains that may be repatriated to Native American groups in the United States and other Native peoples around the world (Weiss, 2008c). NAGPRA (which stands for the Native American Graves Protection and Repatriation Act) along with state laws have been deleterious to the study of the past; many of the collections that were once studied have now been reburied. You may have noticed in this textbook that Old World samples and South American samples are predominantly discussed that is because North American samples are in threat of reburial or have been reburied. South American politics of nations has fragmented the tribal identity and, thus, repatriation has yet to take hold in South America (Weiss, 2008b). In Europe, cultures that celebrate the display of remains and have a long history of treating the human body as art seem to have less problems associated with using human remains in understanding the past; examples of this can be seen in exhibits such as Body Worlds and the strong enthusiasm for the 5000-year-old Alpine Ice Man study (Weiss, 2008b).

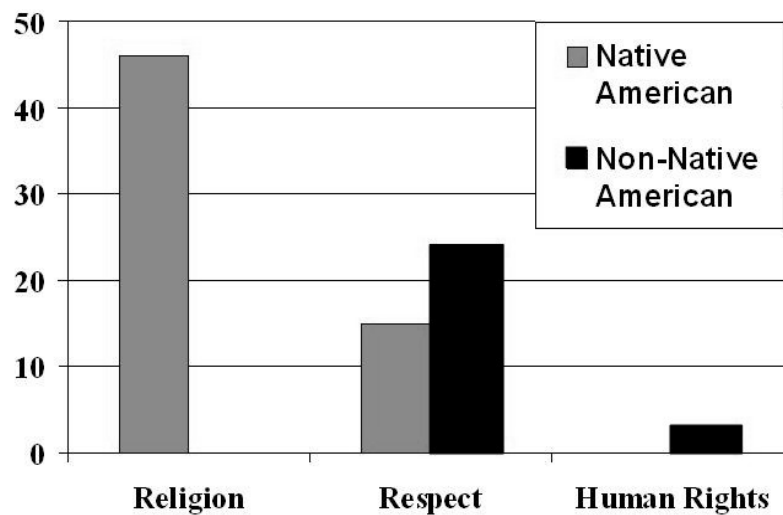


Figure 9.1. Distribution of reasons for reburial as noted from newspaper quotes. Taken from Weiss (2008c).

Furthermore, a strong desire for knowledge and an emphasis on science has endured in Europe, whereas, in the Americas (especially North America) religious sentiment from Native Americans and other residents seems to hinder scientific advancement. It is interesting to note that academics often coach the reburial and repatriation laws as human rights laws or about respect, but Native Americans see the fight for their remains as a religious issue (Weiss, 2008c; 2009b). By examining newspaper articles concerning NAGPRA dating between 1996 and 2008, Weiss (2009b) found from 150 articles: religion is mentioned in 46, respect in 39, and human rights in 3; the remaining articles mention other reasons or do not address the issue. These differences in distribution of repatriation and reburial reasons are statistically significant. In 46 articles, individuals who self-identify themselves as Native Americans bring up religion; however, none of the non-Native American academics mention religion. Respect is mentioned in 15 articles by self-identified Native Americans and in 24 articles by non-Native American academics. These results on Native American and Non-Native American quotes are also significant. Figure 9.1 illustrates these findings.

What this comes down to is that Native Americans most often refer to religious reasons for reburial and non-Native Americans most often talk about respect as the reason for reburial. A couple of quotes to highlight these differences; for example, from Edward Halealoha Ayau of the Hui of Hawaii, we have the quote that he: “firmly believes that the repatriation and reburials were a direct result of intervention by God and the ancestors to inspire and energize us.” Whereas Rubie Watson, the director of Peabody Museum at Harvard, states: “NAGPRA is a human-rights legislation...It was created to heal human wounds.” Religion is the overriding concern of NAGPRA, especially from the viewpoints of the many Native American and non-academic supporters. For example, an email I received from Matthew King, the chief of the Lakota Nation, stated: “After the immigrants came into our country, they started digging for graves, I don’t know why.....They don’t know God.....It [the land] is, a burial ground and also a church for our Indian people.” NAGPRA itself supports the religious implications of repatriation and reburial. One could say that NAGPRA

breaks constitutional law by breaking the First Amendment, which separates Church and State (Weiss, 2009c). For example, NAGPRA states federally funded institutions must perform “in consultation with...traditional religious leaders.” Also, NAGPRA review committees must contain at least two “traditional Indian religious leaders.” Additionally, concepts of sacredness and an emphasis on creation myths are embedded in NAGPRA.

So, why is it that academics deny the religious connection to NAGPRA? Perhaps some of the confusion of the reasons behind reburial may be that respect, human rights, and religion are often intertwined. For Native Americans, respect often means having respect for their religion and creation stories. Emails I received after presenting on the negative effects of NAGPRA on scientific inquiry invoked respect and religion. For example, Kate Henderson, a self-identified Native American, wrote: “...you have no respect for our oral traditions, spirituality, or belief systems...”

Additionally, the United Nations declaration of human rights supports freedom of religion in Article 18. Therefore, supporters of NAGPRA state that the law enables Native Americans to freely practice their religion. Their traditional religions, they claim, include respect for their deceased and creation myths that tell them that they were here from the beginning of time.

It is easy to see how religion, respect, and human rights are intertwined and the main issue behind repatriation and reburial is cloudy. For example, Dr. Ousley and his colleagues at the Smithsonian point out that, in the US, the repatriation debate has been couched in terms of Native American spirituality and human rights vs. the interests of science. Ousley also continuously provides evidence for religious activities in repatriation and reburial at the Smithsonian.

9.2. NAGPRA AND LOSS OF SCIENTIFIC ADVANCES

The consequences to anthropological research due to NAGPRA is that osteological studies containing Native American remains decreased, fewer sites are used, and less geographic locations are examined (Weiss, 2006c). Consequences also include losses of data, funding, time, and scientific freedom (Weiss, 2008c).

Since NAGPRA has been enacted, no one knows with any certainty how many remains have been repatriated or reburied. Federally funded institutions are not required to keep this information and neither is the federal government. However, an article by Jim Erickson about Pueblo reburials in the *Rocky Mountain News*, states that by 2006, 32052 individuals have been repatriated through NAGPRA. Additionally, over half a million funerary objects have been returned to tribes. Some anthropologists are appalled at the prospect of the permanent loss of access to so much knowledge (Weiss, 2008c), and anthropologist Mike O'Brien at Missouri University said that returning bones is like burning books. The loss of data has not stopped, and each year thousands of remains discovered through excavation are returned to Native Americans almost immediately without any scientific study.

Funding and research time has been lost. We cannot calculate the true impact of NAGPRA on museums and other institutions since money going into these institutions is being used to hire individuals to help with inventories and repatriations, rather than research (Weiss, 2009c). Anthropologists have curtailed their research in order to aid in repatriation.

These lost research hours are spent on inventory, consultations, studying the law, and trying to figure out NAGPRA in a sincere effort to be in compliance (Weiss, 2008c).

The worst aspect of repatriation and reburial to me is the loss of scientific freedom. Scientists should be able to attempt to answer all sorts of questions about the world around them, which includes the past. These questions should not be hampered by political or religious sentiments. Loss of scientific freedom is encountered when tribal consultation or supervision is required. Tribes are not likely to allow the study of remains if the questions may be controversial or conflict with their creation myths (Weiss, 2008c). Many Native Americans have strong anti-scientific beliefs; for example, the Malama tribe, who are against all scientific study, and one of their leaders has been quoted as saying: “We advocate against scientific study. In our view, such actions amount to desecration” (Weiss, 2008c). Thus, scientists are being asked to get permission to study human remains from religious people who are often vehemently anti-science.

Thus, it appears that NAGPRA and other repatriation laws have taken their toll on bioarchaeology, but there are many bright spots: studies continue in Europe and we have an eastern European Renaissance. And, even in the United States, anthropologists continue to forge ahead, improving methods and theoretical frameworks to better understand the past.

9.3. POPULARITY OF BIOARCHAEOLOGY

Bioarchaeology is a thriving subject in anthropology, even though access has declined to study Native American remains. The annual proceedings at the American Association of Physical Anthropologists have documented that bioarchaeology topics are the leading type of presentations at the annual meetings and publications of bioarchaeological research fills the journal (Weiss, 2008c). The number of bioarchaeological journal articles has increased over the last three decades; the *American Journal of Physical Anthropology* has continued having a high percentage of osteology publications (Weiss, 2008c). Topics most frequently published in the *American Journal of Physical Anthropology* have consistently related to paleopathology and other bioarchaeological studies with around a quarter of the journal’s articles coming from bioarchaeological research (Weiss, 2008c).

However, the increase in osteological studies not containing Native American remains, both in the *American Journal of Physical Anthropology* and other journals (e.g., *International Journal of Osteoarchaeology*), supports to the idea that researchers may be avoiding remains that are subject to NAGPRA regulations (Weiss, 2008c). In the *International Journal of Osteoarchaeology*, over 90% of the studies conducted on human skeletal remains in the last ten years use non-US remains (Weiss, 2008c). A new journal for bioarchaeology, the *International Journal of Paleopathology*, has been proposed in 2008.

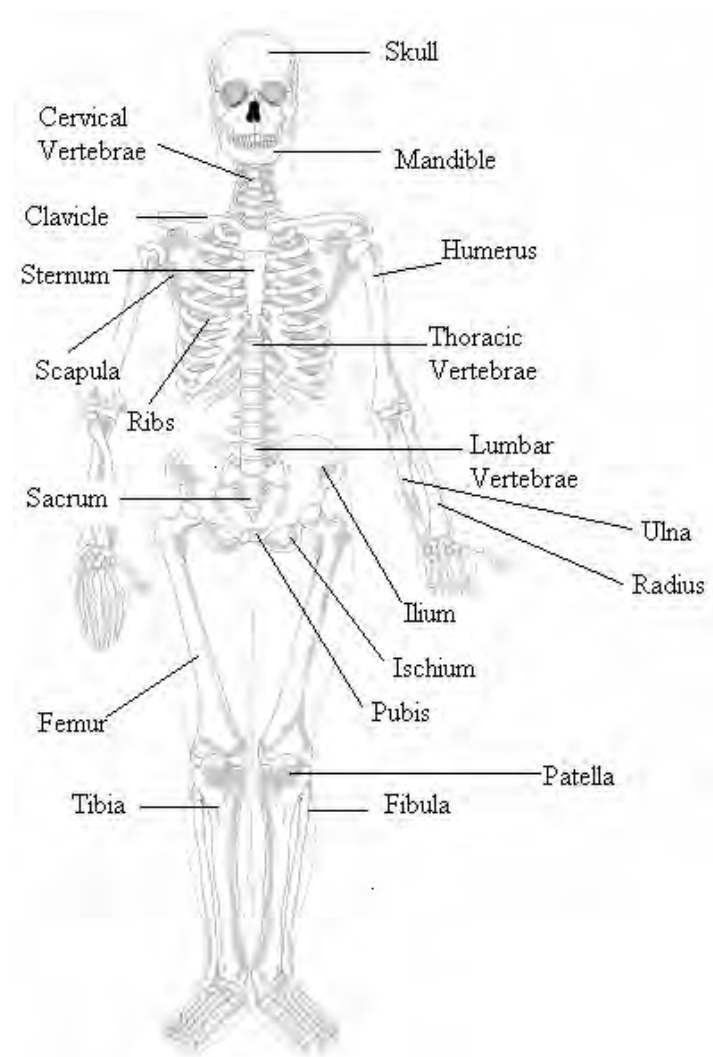
9.4. ADVANCES IN THE FIELD

Within the last twenty years, we have seen the advancement of DNA studies, isotopic research, cross-sectional research, and other methods that have helped us understand the past. Furthermore, we have fine tuned some of the older, less costly, techniques to include

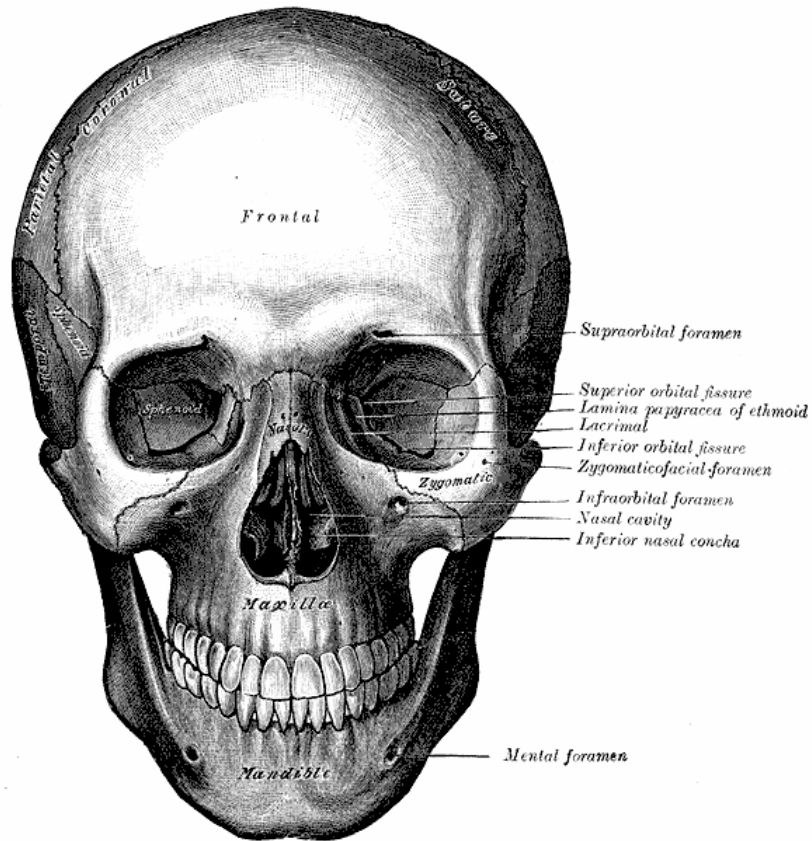
standardization for body size, understanding of which elements are useful for dietary reconstructions and which are useful for biological relationships, and what osteoarthritis scores can best help to reconstruct activity patterns. Along with the bioarchaeological literature, advances in clinical research has helped us understand bone biology and, thus, helped us better utilize skeletal remains to tell the true story of the past.

Additional challenges that anthropologists face is the standardization of data collection, especially if data is lost to repatriation. Better theoretical frameworks must be promoted in order to avoid circular reasoning and better test hypothesis. New research will require large sample size along with better ways to control for noise from biological influences for reconstructing activities and noise from environmental influences for reconstructing biological relationships. Nevertheless, in the short time that bioarchaeology has taken hold, we have seen many advances and a flourish of information that has helped us better understand the past and the people who occupied the world during those past eras.

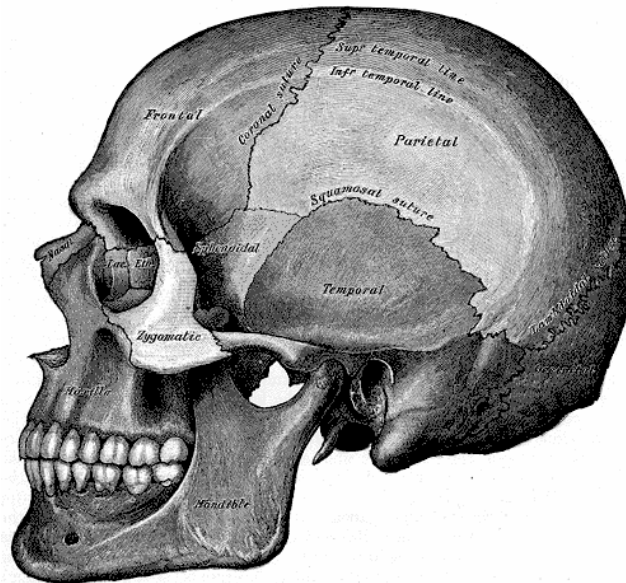
APPENDIX: SKELETAL ANATOMY



Human male skeleton; Author/Artist LadyofHats Mariana Ruiz Villarreal.



Human Skull, Frontal View. Gray's Anatomy (20th US Edition); originally published in 1918.



Human Skull, Side View. Gray's Anatomy (20th US Edition); originally published in 1918.

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