Bones of the Past: Determining Activity Patterns from Skeletal Remains

An Honors Thesis (HONRS 499)

By

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Abstract
As an individual walks, lifts, pushes, and generally moves throughout their lives various stresses are placed upon the skeleton. As a living material, bones react in specific ways to these forces. This process causes changes in the bone that can be seen long after death. Thus by examining these changes in archaeological skeletal remains bioarchaeologists can determine past activity patterns. This paper examines the various methods of doing this. It is divided into two parts. The first part of the paper reviews another project I completed for the National Science Foundation Research Experience for Undergraduates (NSF REU) program in bioarchaeology during the summer of 2008. In this project a partner and I examined the prevalence of degenerative joint disease (DJD) in a skeletal sample from Bab edh-Dhra’, a Bronze Age site in Jordan. We then compared our findings to many more sites from different geographical areas and times. I will not only review our findings in that project, but will also expand upon it in an attempt to find the cause behind differences in the prevalence of DJD between different skeletal sample. The second portion of the paper reviews other ways of determining activity patterns from bone and the many questions about culture they can answer.

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Introduction
Archaeologists seek to reconstruct the lifestyles of past cultures. One way to do this is to examine the bones of these people themselves. Not only does the skeleton absorb nutrients and other materials to preserve information on what an individual ate and where he lived, but as an organic material bone reacts to stresses placed upon it. This leaves in the archaeological record an account of the forces experienced by the body during life and from these skeletal changes activity patterns can be reconstructed. There are many different methods of investigating stresses to the skeletal system, such as observing the geometric properties of bone (Ruff and Hayes 1983;
Ruff et al. 1984; Bridges 1991; Larsen 1997; Ruff 2000; Berner et al. 2007; Sládek 2007; Marchi 2008; Marchi and Sparacello 2008) or marks left by muscles, tendons, and ligaments (Wiess 2003, 2007; Molnar 2006). Another popular method for recording bone stress is to examine the prevalence of degenerative joint disease, or DJD, on the articular surface of bones. This method was the focus of a National Science Foundation Research Experience for Undergraduates (Stanley and Rindler 2008) program in bioarchaeology I attended at Notre Dame University the summer of 2008. During the program a partner and I studied DJD in the distal articular surface of the tibia bones from Bab edh-Dhra', a Bronze Age site in Jordan. This paper will relate the findings of that study as well as expand upon it, and also explore other ways of determining past activity levels from skeletal samples.

**DJD in Bab edh-Dhra’**

The site of Bab edh-Dhra consists of a wall town and cemetery located on the Dead Sea plain of Jordan, just to the south of the bank of the Wadi Kerak. The site was occupied during the Early Bronze Age (EB) periods I-IV. One of the aspects that make Bab edh-Dhra an interesting site is the cultural change that archaeologists have documented through time. Each cultural period was accompanied by a change in mortuary custom. During its earliest phase, EB IA, the area around Bab edh-Dhra’ was most likely inhabited by nomadic pastoralist who came there to bury their dead in shaft tombs. Each shaft tomb contained one to five chambers. Chambers usually contained multiple individuals, with long bones piled in the center of the chamber and skulls stacked in a line along the left wall. These were most likely secondary burials, that is the bodies were first interred in other locations and then after the flesh had decomposed the remains were later reburied at Bab edh-Dhra’, probably on a seasonal basis. Later, during EB IB, a small
village, the first permanent settlement at Bab edh-Dhra’, appeared along with circular, above-ground charnel houses. Bodies were placed in the charnel houses, and once the flesh had decayed the bones were shoved against the walls to make room for new remains. Bab edh-Dhra’ reached its height during EB II-III. During this period the town grew in size and wealth and a large fortified wall was built around the settlement. The people of Bab edh-Dhra’ at this time interred their dead in large, rectangular mud brick charnel houses (Rast and Schaub 2003). The sample of our study came from one of these latter charnel houses, known as A-22. A-22 has a minimum number of individuals (MNI) of around 200. Like the previous charnel houses of EB IB, primary burials probably took place here. Again older bones were moved against the walls to make room for newer bodies. This caused the bones to be heavily intermixed, representing nearly every age group and both sexes (Ortner 2008). During some point in its history A-22 was burnt, causing varying degrees of fire damage in the sample (Chesson 2007)

DJD is a common disease that occurs in humans and other mammals. It is the breakdown of hyaline cartilage in synovial joints. There is debate on what exactly initially causes DJD; age, weight, sex and genetics have all been shown to be contributing factors (Weiss and Jurmain 2007, Jurmain 1977). However it is accepted by many scholars (Larsen 1982) that repeated impulse loading on the joints caused by activity patterns is one of the causes of DJD. The stress placed on the cartilage causes the collagen fibers within it to begin to break down. This may lead to a loss of structural integrity that leads to large scale degeneration in the cartilage called fibrillation (Woods 1995). As the cartilage breaks down nutrition-providing fluids are washed away from the joint and it is less able to distribute loads evenly, further accelerating the process of degeneration. As the hyaline cartilage breaks down the subchondral bone of the articular surface below it begins to fracture and attempts to remodel itself (Lee 1974). This causes
distinctive characteristics such as porosity, lipping, osteophytes and eburnation (Jurmain 1991, Bridges 1993). It is these characteristics that can then be seen in skeletal samples. Porosity is pitting on the articular surface of the bone. They can be small pinpoint sized depressions or multiple pits can coalesce to form larger lesions. Porosity is usually associated with slight to moderate cases of DJD (Nagy 2000). Another sign of DJD is lipping, the formation of an outcropping or ridge along the margins of the articular surface (Lee 1974). Osteophytes are bony outgrowths on the articular surface itself. They are a latter manifestation of DJD (Woods 1995). Eburnation is the presence of a smooth, polished area on the articular surface of the bone. This indicates where the cartilage of the synovial joint has degraded to the point where the subchondral surface of one bone is articulating directly with another, causing them to grind on each other. This is seen in severe cases of DJD (Nagy 2000).

For our project, in order to determine the severity of DJD in the Bab edh-Dhra’ sample we devised a scoring system based on the four indicators listed above. Porosity, lipping, osteophytes, and eburnation were each scored separately from 0 to 3, with 0 signifying the indicator was not present and 3 being the most severe. The scoring methods we used were based off of those found in Ubelaker and Buikstra (1994), Standards for Data Collection from Human Skeletal Remains. If a particular indicator could not be scored for, for instance if part of the bone was damaged or obscured, then it would be given a score of NS or not scorable. These separate scores were then combined into an overall score for DJD. This was again on a 0-3 scale, with 0 being not present and 3 being severe. The prevalence of DJD is affected heavily by age, however because of the damaged and comingled state of the remains age ranges could not be determined for individuals. Because of this we scored only those distal tibias from full adults, not accepting

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any bones with un-fused or partially fused epiphyses. We also marked bone as not applicable (NA) if less than 75% of its articular surface was present (Stanley and Rindler 2008).

In our results we found a relatively low prevalence of DJD in the Bab edh-Dhra’ sample. Of the tibias, 95.8% out of 96 lefts and 97.6% out of 83 rights showed signs of DJD. However, all of these were scored from 1-2. None were scored with a 3 or higher. The average score for left tibias was 1.05 and the average score for right was 1.16. Porosity was the most common indicator of DJD found, ranging in severity from 0-3. Lipping was also present, but no instances were scored above a 2. No examples of osteophytes or eburnation were found. This conforms to the only slight degree of DJD found throughout the sample. Unfortunately, due to the comingling of bones found in charnel house A-22, there could be no comparison between age groups or sexes in our study. We did however used fisher’s exact test to statistically compare right and left tibias and found no significant differences (Stanley and Rindler 2008).

The Bab edh-Dhra’ sample was also compared to other skeletal collections from many different geographic regions and time periods. Of these, six showed statistically significant differences from our sample. In or original project for the NSF REU, we were able to explain the differences in prevalence of DJD between some of these sites and Bab edh-Dhra’, while others we were less certain of (Stanley and Rindler 2008). This was partly because of a lack of time to research fully the cultural and environmental context of these skeletal collections. Since the conclusion of the REU program, I have done more independent research into these sites, and I believe I can now explain most of the causes between these differences in prevalence of DJD.

Of the sites that showed a difference to Bab edh-Dhra’, four had significantly greater amounts of DJD. Shamanka II and Khuzhir-Nuge XIV both represented prehistoric hunter gather populations in Siberia. These people had to walk long distances over rough, steep terrain in order
to access hunting and fishing grounds (Lieverse et al. 2006). In our original project, my partner and I concluded their high level of mobility combined with the rough environment would place stress on the ankle, causing the development of DJD (Stanley and Rindler 2008).

For Shamanka II and Khuzhir-Nuge XIV, their high prevalence of DJD compared to Bab edh-Dhra’ is likely the result of differences between subsistence strategy and mobility patterns. For Wadi Faynan, in Jordan, and Rehovot, in Israel, however, these differences are harder to explain as both these sites represented sedentary agriculturalist societies in similar environments as Bab edh-Dhra’. The population of Wadi Faynan was engaged heavily in copper mining (Abu Karaki 2000). This strenuous activity may have placed more stress on the body as a whole, causing the high amounts of DJD seen in the skeletal remains. The people of Wadi Faynan would also have to travel up steep mountains and hills to access the mines as well as navigate narrow, most likely uneven, mine shafts. The difficulty of the terrain may have led to the high prevalence of DJD. However landscape of Bab edh-Dhra’ was also rough and uneven, so whether or not terrain is responsible for the differences showed in levels of DJD between the two sites is difficult to access. The high levels of DJD in Rehovot surprised even the author of the study done on the skeletal remains. Perry (2002) attributes the high prevalence of DJD here to the possibility that individuals participated in agricultural activities from a very early age. She also cautions that further analysis of osteoarthritis in Rehovot must consider other variables such as genetics or age (Perry 2002).

The remaining three sites all showed significantly less DJD than Bab edh-Dhra’. The populations these sites represent were all sedentary like Bab edh-Dhra’, so the difference in prevalence of DJD must arise from some other factor. Despite being hunter-gatherers, the people of Chiggerville lived in an environment that was rich enough in resources that it was possible to
form a relatively sedentary society. Their subsistence strategy revolved primarily upon gathering easily accessible shellfish and nuts (Sullivan 1977). The population at Chiggerville did not engage in strenuous activities associated with intensive agriculture such as plowing fields or digging irrigation ditches. Nor, unlike the people of Bab edh-Dhra’, did they need to travel over steep and rough terrain to reach fields. The people of Chiggerville’s sedentary settlement pattern, along with the relatively little physical demand involved in their subsistence strategy, most likely contributed to their lack of DJD. Both the Pickwick Mississippian (Larsen 1982) group in the Southeast United States and Ayalan in Ecuador (Ubelaker 1981) are skeletal samples from sedentary agricultural groups like Bab edh-Dhra’, so it may be expected that they show similar amounts of DJD. However the fact that agriculture was often less intensive in the Southeastern United States and Ecuador than in the Middle Eastern Bronze Age, for instance lacking irrigation, may explain these sites’s relative lack of DJD. It may also be possible that Pickwick and Ayalan had more even and gentler terrain than Bab edh-Dhra’, causing less strain on the ankle.

In the original project, we concluded that none of the factors in the environment or culture of Bab edh-Dhra’ caused significant amounts of DJD. When we compared it to other sites, we could explain some of the significant differences, but for others we were less certain. I believe that that I have explained more of these differences. Many of these explanations revolve around the subsistence strategy and settlement pattern of the people. However, some samples, like Rehevolt, remain a mystery. From this I conclude that while the mobility and subsistence strategy a population plays a large role in the prevalence of DJD, additional factors such as must be taken into account (Stanley and Rindler 2008).
Other Methods of Determining Activity Patterns

There are many ways of determining activity patterns in archaeological skeletal materials besides examining the prevalence of DJD. Many of these methods center around the fact that bone reshapes and reforms itself in response to the mechanical loads placed upon it. This is often called Wolff’s Law (Ruff et al. 2006). Since bone responds to the forces placed upon it in this way, differences in the morphology of skeletal samples can be used to examine differences in the activities of past populations. The idea that bones adapt to their mechanical environment, has been supported by many experiments with animal subjects and studies on human athletes (Larsen 1997; Ruff 2000). The modern take on the bone modeling and remodeling processes is that they are a response to strain and it works to achieve an “optimum customary strain level” within the bone. If strain is increased, for instance through greater activity, more bone tissue will be laid down to strengthen the bone, reducing stress and reaching optimum customary levels again. Similarly, if strain is reduces, perhaps through inactivity, bone will be reabsorbed until the optimum customary strain level is achieved. This forms a feedback loop that keeps stress within the bone at equilibrium (Ruff et al. 2006).

Biomechanical studies determine the type and amount of forces placed upon a bone based on its morphology. This can be done by applying the engineering concept of beam theory to long bones. Beam theory states that when a hollow beam, such as a long bone, is bent the mechanical stress is higher the further the distance is from the neutral axis; the central axis where no stress occurs. A beam is stronger and more resistant against bending the more area it has away from the neutral axis. Thus by applying Wolff’s law it can be inferred that a bone when undergoing stress will deposit the most tissue perpendicular to the neutral axis of the force being placed upon it. By
examining the area and distribution of material in bones then, it is possible to determine the forces placed upon it during an individual’s lifetime (Larsen 1997).

The strength and rigidity of bone when compared to certain stresses can be determined through the study of the bone’s cross sectional geometry. Measurements of interest of a bone’s cross-sectional area include cortical area or CA, and second moments of area, I. CA is directly related to a bone’s strength against pure compressive forces applied equally throughout the bone, however, because of factors such as the shape of a bone and the effects of pulling by muscles long bones more often experience bending and torsional forces. I measures a bone’s rigidity under bending forces along certain axis. Especially important are the maximum and minimum resistance against bending forces in the cross section, Imin and Imax (Ruff and Hayes 1983; Larsen 1997; Ruff 2000).

Cross sectional geometry studies are often used to look at differences in the activities and physical state of ancient populations due to changes in subsistence strategy, mobility, or gender roles in labor. Many studies have been done on the transition of populations from hunter-gatherers to agriculturalists. One example, Bridge’s (1991) study on a Mississippian population from Pickwick Basin in Alabama, show that long bone strength increased with the adoption of agriculture, especially in the legs of males and arms in females. This suggests a more physically demanding lifestyle with the adoption of agriculture. On the other hand, studies such as Ruff, Larson and Hayes’ (1984) on prehistoric people of the Georgian coast showed the opposite; a decrease in long bone cortical area and presumably less mechanical stress due to the adoption of agriculture. These apparently contradictory studies show that there is no consistent set of changes in long bone morphology caused by the transition from a hunter-gather to agricultural. Rather,
differences in technology used, divisions of labor, and other kinds of resource exploitation, must be taken into account.

One aspect of behavior often associated with different subsistence strategies that can be examined by cross sectional geometry is mobility. Since the lower limbs are involved primarily in locomotion, differences in mobility should be reflected in differences in lower limb morphology. This is especially true for the mid femur and tibia, where the stresses produced from locomotion are the greatest (Ruff and Hayes 1983). Measures of long bone strength, such as CA% and second moments of area, may be used to determine the activity patterns of the lower limbs and thus make inferences on mobility levels. However, in addition to mobility, the femur may also be highly influenced by body shape and climate, making the tibia a more reliable indicator of mobility. Also, some studies indicate that terrain, and not mobility patterns or subsistence strategy, may have the greatest effect on lower limb robusticity (Ruff 2000; Marchi and Sparacello 2008). When comparing several different samples from the United States, Ruff (2000) found that sites showed little difference in femoral robusticity between different subsistence strategies once terrain was factored out. In Marchi and Sparacello’s (2008) study two different populations, mobile Neolithic pastoralist and sedentary Medieval fishermen, living in the same geographical area showed similar levels of femoral robusticity. An alternative measure of mobility is the shape of the long bone diaphysis. This is determined by taking the ratio of \( I_{\text{max}} \) to \( I_{\text{min}} \). An \( I_{\text{max}}/I_{\text{min}} \) ratio close to one indicates a circular shape while a ratio greater than one is less circular. This shape reveals the intensity and direction of bending forces placed on the bone. If the diaphysis is circular the bone experienced primarily compressive forces or equal bending forces in all directions, whereas bending force in one direction causes a more elliptical shape. In the femur and tibia, walking, jogging and running cause anterior-posterior bending
forces within bone while having little effect in the medial-lateral direction. Thus following beam theory, cortical tissue will be redistributed towards the posterior and anterior in the lower limb bones of highly mobile individuals, causing a increase in the Imax/Imin ratio, whereas those of more sedentary individuals will remain relatively circular (Ruff and Hayes 1983). In the same study cited above, Marchi and Sparacello (2008) found that even though both populations had similar levels of robusticity in the femur, its shape was more circular in the Medieval sample compared to the Neolithic pastoralists.

Along with differences in lower limb morphology and mobility, biomechanics can also examine changes in behavior relating to the use of the arms. In humans, the use of the arm on one side of the body is usually favored over the other. This favoritism is reflected by differences in the morphology of the bones in either arm, especially the humerus. The presence of a difference between the upper limbs on different sides is called bilateral asymmetry. As some activities require one arm, for example swinging a tennis racket, while others require two, rowing a boat, changes in bilateral asymmetry within a population can reflect changes in activity patterns. Ways to measure humeral bilateral asymmetry include humeral length, distal articular breadth, and cross-sectional geometry, however, humeral length may be affected by environmental and genetic factors and articular breadth does not change in response to mechanical loading (Berner et al. 2007). A decrease in bilateral asymmetry is often seen with the adoption of agriculture, especially among women (Berner et al. 2007; Bridges 1991; Ruff 2000). Patricia Bridges (1989) explained the decrease of bilateral asymmetry among females between Archaic and Mississippian populations as the result of using both arms in grinding corn with a wooden mortar and pestle. Changes in technology, as well as subsistence strategies may
also affect bilateral asymmetry. For instance, the use of a spear-thrower would primarily involve only one arm, whereas using a bow would involve both (Bridges 1991).

One aspect of culture that cross-sectional geometry studies can reveal is the sexual division of labor. In many cultures males and females perform different task causing sexual dimorphism in bone morphology. The degree and pattern of sexual dimorphism may differ according to subsistence strategy. One trend seen is skeletal samples is that mobile hunter-gatherer populations tend to show more sexual dimorphism than sedentary agriculturalists of industrial societies. This is especially evident in the lower limbs where males of hunter-gatherers tend to have greater robusticity and less circular femoral and tibial diaphysis than females. This is because it is often males who engage in long-distance activities like hunting while females are more involved in short range food acquisition and domestic task (Larsen 1997; Ruff 2000). This sexually dimorphic mobility pattern is also seen in pastoralists, where males traveled great distances leading their flocks to pastures (Marchi 2008). This mobility difference does not exist in agricultural societies, in which both sexes are sedentary. Sexual dimorphism also shows in the upper limbs. In their study, Marchi and Sparacello (2008) attributed significantly more robust humeri in the males of both Neolithic and Medieval population to more physically demanding task than females. They also attributed a greater prevalence of bilateral asymmetry in the upper limbs of males in the Neolithic population to differing task; unimanual activities such as the use of stone axes for woodworking among males, and bimanual activities such as processing grain for females. Sexual dimorphism in bilateral asymmetry was also present in a late Eneolithic and Early bronze age population in a study by Berner et al. (2007). The authors concluded that males in this population participated in activities associated with intensive agriculture that caused stress
to be placed unilaterally on the upper limbs, while females were involved in domestic activities such as weaving that caused equal mechanical loading in both arms.

As well as the mechanical stresses placed on them by activities, bones respond to the pushing and pulling forces of the muscles, tendons, and ligaments that attach to them. The effects of this can be seen in musculoskeletal stress markers, also known simply as muscle markers. These occur where muscles, tendons, and ligaments insert into the bone to access the blood-supplying perisoteum and the bony cortex underneath. When these areas are subjected to stress from muscle activity, blood flow increases stimulating bone forming cells that cause bone hypertrophy and create distinct skeletal markings and bony projections. Muscle markers are thought to be the result of repeated and habitual muscle use; the more active the muscle is, the bigger the stress marker. Thus anthropologists can look at musculoskeletal stress markers to determine activity patterns. Like cross-sectional geometry studies, muscle markers have been used to examine many aspects of past life styles, including sexual divisions of labor, changes in subsistence strategy, and specific cultural activities (Weiss 2003, 2007). In a study done on Stone-Age population on an island in the Baltic Sea, Molnar (2006) related patterns of muscle markings with specific activities such as archery, harpooning, and rowing. However, in addition to physical stresses, the size and definition of muscle makers also correspond with several other factors. Studies have shown muscle markers correlate significantly with age. Researchers believe that this is the result of continued use of muscles over long periods of time. Because of this age has to be considered when interpreting past activity patterns (Weiss 2003, 2007; Molnar 2006). Body size also effects muscle markers, and must be standardized for. Bigger muscles and bigger bones result in larger muscle markers. Some studies have shown in fact that muscles markers result from body mass more than activity, however since the upper limbs do not play a role in
weight-bearing, they should be free from this effect (Weiss 2003, 2007). Many studies have also shown correlations between muscle markers and gender. This has been interpreted as evidence of sexual divisions in labor (Molnar 2006). However, further research has shown that these differences in muscle makers may actually be due to size differences between sexes rather than separate task performed by males and females (Weiss 2003, 2007). In her study Weiss (2007) found that for many muscle insertion sites significant differences in sex disappeared once size differences were factored for. However, correlations with sex remained for some stress makers, indicating that they reflected actual divisions in activity. The specific muscles markers involved in males may have resulted from the use of throwing spears in hunting and interpersonal conflict. Some studies done on muscle markers have produced conflicting results with cross-sectional geometry studies done on the same samples. This may put into doubt the use of muscle markers in determining activity patterns, however Weiss (2003) found that once aggregated, scores for stress makers correlated with cross-sectional robusticity.

Discussion and Conclusions

The above methods of studying skeletal remains can yield a great amount of information about past life ways. One interesting exercise would be to use these methods to reexamine the sample from Bab edh-Dhra examined in my study of DJD in the distal tibia. Since the size and definition of muscle markers in the lower limbs seem to be influenced by body weight rather than activity patterns, an examination of musculoskeletal stress makers on the tibia may not yield much pertinent information. Performing a cross-sectional geometry study on the Bab edh-Dhra’ sample maybe be difficult due to the relative scarcity of intact tibia shafts and the fact that some bones that have undergone significant fire damage may have had their geometric properties
altered, however it may still be possible. The cross sectional geometry of the bone would reveal how
the prevalence of DJD in the ankle relates to the amount of mechanical stress experienced by the tibia, and if the two correlate at all. Evidence indicates lower limb robusticity is related to terrain while long bone shape correlates more with mobility. Because of this it would be interesting to compare the amount of DJD in the tibias of Bab edh-Dhra' and multiple other sites in relation to their robusticity and shape. This would reveal whether terrain, mobility, or other factors are the main cause of DJD in the tibia. Because the people of Bab edh-Dhra' were sedentary and living on step and rugged terrain, I would hypothesize that their tibias would be relatively robust and circular.

One of the primary interests of archaeologists is discovering what people of past cultures did in their everyday lives. Fortunately, this information is preserved in the skeletal remains of these people themselves. I first learned of this in my study of Degenerative Joint Disease at NSF REU in bioarchaeology at Notre Dame. I have since done more research in other ways of interpreting activity patterns, including cross-sectional geometry and muscle markers. All of these methods are based on the fact that bone as a living material reacts, responds, and adapts to the forces places upon it. By combining all of these different studies it is possible to create a more detailed picture of the lives of ancient peoples.


Larsen CS. 1982. St. Catherine's Island. Anthropol Pap Am Mus 57:159-270

Lee P, Rooney PJ, Sturrock RD, Kennedy AC, Dick WC. 1974. The etiology and pathogenesis...


Weiss E. 2007. Muscle markers revisited: Activity pattern reconstruction with controls in a
