THESIS

MUSCULOSKELETAL STRESS MARKERS: A COMPARISON BETWEEN A 3D DIGITIZING GEOMETRIC MORPHOMETRIC APPROACH AND A MORE TRADITIONAL SCORING METHOD USING CLAVICLES FROM A 19TH CENTURY ASYLUM COLLECTION FROM PUEBLO, COLORADO

Submitted by

Kimberly Griffith

Department of Anthropology

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Master's Committee:

Advisor: Ann Magennis

Michelle Glantz
Mark Frasier

ABSTRACT

MUSCULOSKELETAL STRESS MARKERS: A COMPARISON BETWEEN A 3D DIGITIZING GEOMETRIC MORPHOMETRIC APPROACH AND A MORE TRADITIONAL SCORING METHOD USING CLAVICLES FROM A 19TH CENTURY ASYLUM COLLECTION FROM PUEBLO, COLORADO

With the availability of more sophisticated equipment for measuring and analyzing data, it is tempting to disregard older, simpler methods. However, these newer methods require expensive equipment, complex procedures and statistical know-how that more traditional methods do not. In this study, I attempt to determine whether new methods of analyzing musculoskeletal stress markers are a better reflection of that muscular stress than more traditional methods.

The traditional method of analyzing musculoskeletal stress markers is to score them based on the rugosity of the attachment site. In this study a 1-6 scale was used for the attachment site of the *costoclavicular ligament* on the clavicle. The results of this study were then compared to results obtained from using a 3D digitizing MicroScribe, used to map the surface of the costoclavicular ligament, along with the attachment sites of the *pectoralis major muscle* and *deltoideus muscle* on the clavicle. The data from the 3D digitizer was analyzed using several different software programs designed for landmark-based geometric morphometrics.

The study sought to answer whether the same differences are observed in regards to age and sex when various analyses are used. The traditional method provided an average score that shows males to be more rugose than females at the attachment site of the costoclavicular ligament, whereas the analysis of shape difference done with the 3D digitizing shows that males were only statistically significantly different than females on the right attachment site, but not on the left. Age results included four categories (20-29, 30-39, 40-49, 50+) and the results of the scoring suggest that there is a gradual change with age, but that rugosity is not controlled by age. The results from the 3D digitization support this, with statistically significant differences in shape observed between the youngest and oldest age group.

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CHAPTER 1: INTRODUCTION

The investigation of activity patterns, or occupation, is an important aspect of anthropology; showing how people lived, what they ate, and what they did in their spare time. Although in some cases ethnographical evidence exists describing what members of a cultural group participated in for sustenance and non food production-related activities, some groups are only known from objects they left behind; such as buildings, projectile points, and writing. Not all groups throughout history have used the written word though, and even those who did may not have had the interest to write about daily activities, or the writings might not have survived or been translatable. Therefore, it is important to try to glean activity patterns from any source that is left by a group. Osteological, or skeletal, remains are more likely to survive for long periods of time than writings, due to the fragile nature of paper or parchment. Skeletal remains can tell you not just what a group participated in but what an individual's role was within a group.

There are many ways in which human remains can be used to identify activity patterns. Diet and dental care can be observed through wear patterns on the teeth, caries, abscesses, and dental modification, such as fillings. Other signs of nutrition can be gleaned from cortical bone thickness or bone asymmetry, with malnutrition being expressed by less cortical bone and more asymmetry. Violence in a society can be viewed through healed broken bones and bone penetration patterns from weapons. Different positions of sitting can create facets on bone from the pressure of the rest of the body. Even signs of arthritis can show what parts of the body were being used more than others. Another method used to analyze activity patterns, is looking at the places that muscles and ligaments attach to bones, called musculoskeletal stress markers. They are called stress markers because these areas are prone to change when the muscle attached there grows or is injured through use. While it is important to be able to interpret activity patterns based on established methods, there is also value in trying to find new methods; new markers of activity patterns and new ways to explore and interpret them.

This study is focused on musculoskeletal stress markers, the methods used to interpret them, and what these methods can actually say about activity patterns. Two methods will be compared in this study, using clavicles from 69 individuals from the late nineteenth century Colorado Mental Health Institute at Pueblo collection dating from 1879-1899. The traditional method of scoring musculoskeletal stress markers are compared with a method involving the use of a 3D digitizer. The traditional method involves assigning an ordinal score based on the terrain of the musculoskeletal stress marker. Using the 3D digitizer, in this case a MicroScribe (Immersion Corporation), the musculoskeletal stress marker can be digitally mapped and various software is used to look for differences in shape.

There are multiple questions this study seeks to answer using these two methods: does either method show a difference between males and females, do age groups vary using either method, what is each method showing, and which method is more useful? According to what we know about the time period that this skeletal collection is from, we would expect to see a sexual division of labor that would lead males to be more developed muscularly than females. Age also has an effect on the expression of musculoskeletal stress markers, with continuous use of a muscle during the working part of an individual's life we would expect that muscle to increase in size and in doing so have a larger site for attachment on bone. Although younger individuals are capable of showing the same degree of musculoskeletal stress as older individuals, it is expected that there is a difference in age groups for both methods explored. Both methods are utilized to see whether there are male-female and age differences in the collection, and an interpretation can be made as to what those differences are and why. The 3D digitizer allows for males to be looked at as a whole and instead of a general change that is expressed through an average score as would be identified in the traditional method, specific areas can be identified that differ between groups. For example, the male average of one musculoskeletal stress marker in a collection might be a 5 and the female a 3. The conclusion from this would be that males have more variation in terrain on that musculoskeletal stress marker and used that muscle more frequently than the females. Using the 3D digitizer and MorphoJ (Klingenberg 2011), one can take the shapes of the male and female musculoskeletal stress marker and find an average male shape and an average female shape and then compare the two, revealing not just that they are different but the specific areas of the musculoskeletal stress marker that vary. It is then important to ask what one is gaining from each method and what information is lost. The traditional method has a predetermined categorization of musculoskeletal stress markers that are assumed to represent a gradual increase in stress placed on the muscle involved. The traditional method is not reliant on expensive equipment, or complex statistical procedures, so that anyone with some training can perform an analysis of musculoskeletal stress markers. More detail on musculoskeletal stress markers, the methods used in this study, and the results will be given in the following chapters.

Musculoskeletal stress markers have been explored in the past and Chapter 2 explains the background for their study; defining musculoskeletal stress markers, summarizing previous research, and describing the traditional method of analyzing them. Chapter 3 reviews the methods used in this study, including both procedural and data analysis methods. The procedures described are both those using a traditional method to quantify rugosity and those used to collect data with the 3D digitizer. While the analysis of data gathered by the traditional method was straight forward, the statistical procedures were quite involved for data collected with the 3D digitizer. Chapter 4 details the results of the study for both the traditional method and the use of the 3D digitizer in looking at musculoskeletal stress markers. This includes comparisons of males and females and the different age groups in the sample, using both methods to determine their similarity or differences. The discussion chapter will conclude this paper, explaining the results of this thesis and determining the degree of success in answering the questions regarding what can be said about differences in sex and age for each method.

The merits and flaws for each method will be discussed and directions for future research in using a 3D digitizer to analyze musculoskeletal stress markers will be suggested.

CHAPTER 2: MUSCULOSKELETAL STRESS MARKERS

The idea that some aspects of human anatomy are related to occupation is not a new one, having been documented as early as 1556 (Wilczak and Kennedy 1998: 461). Many terms have been used for this concept, including robusticity, enthesopathy, musculoskeletal stress markers (MSM), markers of occupational stress, and the more generalized term, life stresses. These indicators relate not just to the occupation of an individual, but to lifestyle and behavioral habits. Robusticity describes the normal variation of markings of musculoskeletal attachment, including both tendons and ligaments (Hawkey and Merbs 1995:328). Another term that can be used for robusticity is entheses. Entheses are where muscles, tendons, or ligaments insert into bone (sometimes enthesis is used only to refer to muscle and tendon attachment, and the term syndesmosis is used for ligaments (Mariotti et al. 2004:146)). Enthesopathy refers to a pathological or abnormal occurrence at the point of attachment. Another term for an enthesopathy can be a stress lesion. A stress lesion is where pitting occurs in the

Figure 2.1 - Lesion where *costoclavicular ligament* attaches to the clavicle.

bone cortex (Hawkey and Merbs 1995:329). An enthesophyte is a boney projection at the site of muscular attachment. Musculoskeletal stress markers (MSM) are where a muscular attachment to bone (both insertions and origins of muscles) causes bone remodeling, leaving an impression on the bone. MSM can include all of the above terms.

Musculoskeletal stress markers are not the only way to gauge habitual activities; markers of occupational stress (Ubelaker 1979, During et al. 1994, Jordana et al. 2006, Judd 2010), and other life stresses, including cortical bone thickness (Ruff and Larsen 1990, Bridges et al. 2000, Mays et al. 2009) have been used. Markers of occupational stress is a broader term that can incorporate musculoskeletal stress markers, but would also include patterns of trauma, arthritis, and pressure facets (Wilczak and Kennedy 1998: 469). Life stresses would include all of the markers of occupational stress, but would also include general signs of health, including child birth, disease, and dental health (Kelley and Angel 1987:199). Cortical bone thickness has been used as a sign of nutrition (Cox et al. 1983), as has asymmetry (Parsons 1990), but recently cortical bone thickness has been used to determine activity patterns. Cortical bone thickness studies consider the shape and size of the bone as a whole and how that is impacted by activity related bone remodeling.

Bone Remodeling

Bone remodeling is a normal process, and is a necessary part of the process of bone growth. Remodeling ensures that the bone is capable of withstanding the pressures put on it by the rest of the body. When the body is developing, bone is continuously growing in size and shape before epiphyses start fusing when the body reaches adulthood. This is known as modeling. After adulthood is reached, bone continues to form and change, and the bone remodels. Some areas are less affected by remodeling after adulthood than others; bone length is less likely to change than width.

Bone is continually remodeling due to stresses that are put on it by the human body. However, there are only a few ways that bone can respond to these stresses and it can either deposit more bone, resorb bone, or both. There are specialized cells in the body that produce bone and cause the deposition thereof; these cells are called osteoblasts. To balance the osteoblasts, there are also cells that are responsible for the removal of bone matrix, causing resorption, that are called osteoclasts. Both of these cell types are a part of normal bone functioning and are involved in removing both old and damaged bone and replacing it by newer bone. This bone remodeling by osteoblasts and osteoclasts plays an important role in the expression of bone disease, the ageing processes, as well as activity.

Bone Disease

Bone disease is a pathological response to multiple conditions, including toxins, infectious disease, fractures, congenital defects, and nutrition (Mann and Murphy 1990:16). These show themselves on the bone through abnormal bone formation, abnormal bone destruction, abnormal bone density, abnormal bone size, and abnormal bone shape (Ortner 2003a:45). In the case of some diseases, the disease does not cause bone deposition or resorption, but create conditions in the body that stimulate osteoblasts or osteoclasts (Ortner and Turner-Walker 2003:14). Because of the limited number of ways that bone can respond, it is oftentimes difficult to determine what the stressor is that caused bone remodeling to occur. It is necessary to examine not only what type of remodeling is occurring, but also the location(s) in which it takes place in order to diagnose the stressor. Very simplistically, the diseases sarcoidosis and leprosy both primarily affect the hands and feet; however sarcoidosis affects the nasal bones, but not the inferior nasal spine and maxilla (Ortner 2003b:341). If only the hands or feet of the skeleton were present, or the face were not affected it would likely be impossible to distinguish these two diseases. Some of these conditions will not appear on the bone at all, because the condition rarely presents itself on the bones or the individual did not survive the condition long enough for it to affect the bones. Other effects are temporary and will disappear if the individual lives long enough to recover and the bone will remodel to a normal state, as in the case of some bone fractures.

Age

As humans age, they are more likely to have experienced stress or disease at some point that affects the skeleton. When an individual lives longer, it is because they were capable of overcoming these stresses. Therefore it is more likely that an older individual will show some sign of stress that a younger individual might not, although the younger individual may have died from the stress-causing condition. It is, however, also possible that the older individual will have had time to completely heal from the stress placed upon the body and normal bone will replace the bone showing signs of the stressor. Some diseases, such as osteoporosis and arthritis, accrue with age and the signs of such are more obvious on the skeleton with time.

Bone is continuously being resorbed and new bone replacing it. Older bone is less resilient than new bone and more prone to damage (Pearson and Lieberman 2004:73). As we age, new bone still replaces old bone, but the bone is being resorbed faster than it is being deposited. This is because osteoclasts can destroy bone matrix more quickly that osteoblasts can deposit new bone. Bone resorption can be stimulated due to lack of calcium and lower levels of estrogen or testosterone can prevent deposition; both calcium and estrogen and testosterone levels normally decrease with age (Ortner and Turner-Walker 2003:22). This decline in hormones with age, combined with demineralization of bones of older individuals, leads to overall bone loss and the frailty we see as humans' age. Exercise helps counteract this, because it increases the bone deposition rate, but this becomes less effective with increasing age (Smith 1974, Ruff et al. 2006:494).

Activity

Activity can be seen on the bone in a few ways: cortical bone thickness and geometry, directional asymmetry, and musculoskeletal stress markers. Cortical bone geometry and thickness causes remodeling based on where stress is placed on the bone. Directional asymmetry in bones begins during development, based on preferential use of arms, generally the right, in humans. Musculoskeletal stress markers are similar to bone disease in that they involve both depositional and resorptive processes on the surface of the bone, but they differ in that they are generally not pathological in nature and they only occur at places of muscle or ligament attachment on the bone.

Increased mechanical strain (due to greater activity levels) causes more bone to be deposited, and thus reducing the strain on bone (Ruff et al. 2006: 485). Mechanical stress on bones increases deposition of minerals and the production of calcitonin, a hormone that hinders bone resorption

(Tortora 1999:120). Decreased strain (due to reduced activity levels) causes bone to be resorbed. The increased strain may be due to a higher frequency or higher magnitude in activity levels. More recently it has been thought that the magnitude plays a greater role than the frequency of activity (Ruff et al 2006). This process occurs on a specific level, where bone is deposited to counteract a specific direction where stress is occurring. This can change the shape of the bone as a whole, widening the cortical bone in one direction, while the other side stays the same. This will make the bone appear more oval than round. Viewing the direction and the location of the remodeling on the bone can give general information on the stresses that were taking place.

Directional asymmetry is the tendency for one limb to be longer or wider than the limb on the opposite side of the body. In humans, it is often the case that in the upper limbs the right side is longer, and in the lower limbs the left side is longer. This is due in part to mechanical loading of the dominant upper limbs, where the right limb will be used for tasks requiring more precision. When bimanual activities are performed, the upper limbs tend toward symmetry. The left lower limb is usually longer or wider than the right because it is used as the supporting limb when kicking or performing other tasks with the right leg (Auerbach and Ruff 2006). Although the right leg is being used for the activity, the left limb is supporting the rest of the body and performing more work. The upper limbs are able to be more directionally asymmetric than the lower limbs because they are not used in locomotion, so it is not harmful if there is more variation in size. However, the lower limbs are used in locomotion, making it necessary for them to be more symmetrical to have a more efficient gait.

Muscles attach to bones and are used to produce movement of those bones. Muscles generally have an origin on a bone, the bone that is stationary during movement, and an insertion on the bone that is moving during an action. The attachment point on the moving bone is likely to suffer more stress than the origin. The same principles that apply to cortical bone thickness and asymmetry apply to some degree to musculoskeletal stress markers on the bone; increased stress causes bone deposition and differential use of the muscles of the right or left limb will show on the bone. Therefore, we would expect that muscle markers will appear more on the insertion point of a muscle on the bone than on the origin. We would also expect that bimanual activity will show itself through symmetric muscle markings, and unimanual activity will appear as asymmetry.

Uses of Musculoskeletal Stress Markers

Not all activities will show themselves on the skeleton, and many activities will express themselves in the same manner, making it difficult to determine what the stressor was. Many times the cultural context will be used to eliminate activities that can create the same anatomical marking. Because there is no way to have experimental control in an archaeological setting, one can only suggest that an activity may have been the cause; it is impossible to know. In the past, authors more commonly would associate a specific MSM hypertrophy to a particular task, but now the more common trend is to propose general activity levels rather than a specific activity.

The majority of research on musculoskeletal stress markers has been conducted with archaeological skeletal collections, although there are potential uses in forensic cases. Archaeological study has been both historic and prehistoric. The goals in these studies are diverse, and include: determining occupation, comparing one group to another group of similar time periods, comparing a group over time to see if and how a historic event impacted a population, exploring sexual division of labor within a group, determining socioeconomic status, and determining whether certain technology and/or tools were used, or some combination of these.

Determining Occupation

MSM has been used to determine specific occupations or habitual activities engaged in by individuals by many authors (Dutour 1986, Galera and Garralda 1993, Eshed et al. 2004, Oates et al. 2008). When trying to determine a specific occupation it is necessary to use more than one marker, and often to bring in other markers of occupational stress, such as trauma and articular facets appearing in abnormal areas. Using MSM alone to determine specific occupations has been criticized for its oversimplification of cause and effect relationships (Jurmain and Roberts 2008).

Capasso et al. (2004) used MSM and fracture patterns in their study of 143 individuals from Herculaneum, killed during the eruption of Mount Vesuvius in 79 AD. They concluded that heavy labor was common in Herculaneum, even in children. They go on to suggest that one of the individuals was likely a boxer, based on nasal and metacarpal fractures and hypertrophy of phalanges and the insertion point of flexor muscles. They suggest that another individual was most likely a javelin thrower; he had exostosis on the epicondyle of the humerus, where the flexor muscles of the wrist and hand attach. This is associated with throwing and swinging grasped objects.

Lai and Lovell (1992) conclude in their study of individuals buried at a Fur Trade Period archaeological site in Alberta, Canada, that 3 of the 14 studied were likely voyageurs. That is, that they transported furs via river, and thus did a lot of manual labor; carrying canoes, paddling, and carrying supplies. Lai and Lovell (1992:225) based their conclusions not just on muscular markings of both the upper and lower limbs, but also on osteoarthritic pathology, and the presence of articular facets.

Comparing Groups

Often musculoskeletal stress marker studies will compare two populations, whether they are in similar regions and time periods, or different regions in different time periods. Studies will look at lower limbs in order to gauge mobility (Churchill and Morris 1998, al-Oumaui et al. 2004) and upper limbs to determine levels of manual labor (Churchill and Morris 1998, Eshed et al. 2004, Lieverse et al. 2009).

Churchill and Morris (1998) looked at upper and lower limb MSM in 75 Khoisan foragers from different environments in order to evaluate differential work load. They found that the upper limb MSM followed their predictions that males living in a forest environment would be more robust than those in a fynbos (shrubland), which was then greater than those living on the savanna. They found no significant differences in females or in the lower limb MSM, which was predicted based on the need to search longer for food in forest and fynbos environments. They conclude that different environments impacted how much work was required for males to acquire food in the various environments, with the forest environment requiring the most effort and the savanna the least.

Steen and Lane (1998) used upper and lower limb MSM, along with markers from the skull in order to compare two Alaskan Eskimo populations. In their comparison of 104 individuals from Golovin Bay and 134 individuals from Nunivak Island, they found that both males and females from Golovin Bay utilized many lower limb muscles important for walking more so than individuals from Nunivak Island. Steen and Lane also found that females from Golovin Bay had more developed pterygoid medialis and masseter muscles, consistent with heavier mastication and using their teeth as tools, than the females from Nunivak Island. Both the lower limb use and mastication are consistent with ethnographic accounts of individuals from Golovin Bay being very mobile and females chewing skins as part of footwear manufacturing.

Comparing Groups over Time

Comparisons of groups over time can inform authors as to whether there was a change in the status quo. Studies have examined MSM in an early group and a later group in order to see if they are similar or if a historical event caused behavioral and consequently physiological change (Lieverse et al. 2009).

Munson Chapman (1997) looked at 185 individuals, using 24 muscle attachment sites of the upper limbs in pre-contact (1200-1450 AD) and post contact (after 1600 AD) Pecos Pueblo, New Mexico. She found a trend for increased MSM robusticity, and therefore increased activity after Spanish contact in Pecos Pueblo. She concluded that there was likely an increase in maize production and overall labor in both sexes as a result of Spanish contact.

Eshed et al. (2004) compared upper limb MSM in Natufian and Neolithic groups in the Levant in order to see whether there was an increase or decrease in physical stress with the advent of agriculture as the primary means of subsistence. Although there was not a significant change in MSM in females, the authors found that males in Neolithic groups had more robust muscle markings on the upper limbs, and concluded that there was indeed an increase in labor associated with the adoption of agriculture in the Levant.

Sexual Division of Labor

Others have also used muscle markers to look at whether males and females were performing the same activities (Munson Chapman 1997, Robb 1998, Eshed et al. 2004, Havelkova et al. 2011). Sexual division of labor speaks not only to cultural ideas of sex, but also relates to subsistence behaviors.

Al-Oumaoui et al. (2004) compared MSM in five populations from the Iberian Peninsula, with dates between 2800 BC and 1300 AD. They looked at populations engaged in different economic activities (agriculture, livestock production, or mixed) and found that different subsistence patterns helped determine sexual dimorphism in MSM. In a comparison of the above groups, agricultural populations showed the least sexual dimorphism in their lower limbs, while populations involved with raising livestock showed the most lower limb dimorphism. This indicates that pastoral males were more mobile than females due to their role in herding animals, while in agriculturalists both sexes were equally sedentary.

Lieverse et al. (2009) looked at upper limb MSM in Middle Holocene foragers in the Cis-Baikal region of Siberia. In the Kitoi (6000-4000 BP) group they found very little difference in musculoskeletal stress markers. In the 35-50 year old adults, Lieverse and colleagues noted that males showed greater prominence in MSM than females of the same age, suggesting that males and females might have performed the same activities but males probably participated more often or at a greater intensity.

Socioeconomic Status

Along with looking at sexual division of labor, Havelkova et al. (2011) used musculoskeletal stress markers to look at socioeconomic status in 9th century Moravia. They compared the remains of those buried at the castle, presumed to belong to the wealthier inhabitants, to the remains of those presumed to be farmers in the hinterlands. As expected, males from the hinterland showed higher levels of upper arm muscle rugosity than those in the castle. Females showed no statistically significant difference when comparing those at the castle with those in the hinterland. The authors suggest that females buried at the castle were engaged in more labor than the males of the castle, and thus had less social standing.

Robb (1998) found a relationship between MSM and grave goods at an Italian Iron Age cemetery, suggestive of socioeconomic status. In general, those with higher frequency and severity of musculoskeletal stress markers had fewer grave goods, but when separated into smaller periods of time individuals of more elite status appear to have more prominent markings of the upper limb. Robb concludes that although there is a relationship between MSM and social status, it is not clear exactly what that relationship is.

Technology/Tool Use

Others are more interested in whether an individual or group practiced specific behaviors, and are usually looking for evidence of technology (Hawkey and Merbs 1995, Kennedy 1983, Peterson 1998, Molleson and Blondiaux 1994). In some cases there is historical evidence of this technology and in others there is only a suggestion based on subsistence strategy.

Kennedy (1983) notes that the supinator and anconeus muscles on the ulna are prominent in archaeological populations from India, leading him to look for other populations that share this trait. He remarked that hunter gatherer populations that use spears, bolas, slings, and boomerangs also show well marked supinator and anconeus muscles. He concluded that these muscles on the ulna are well marked in individuals that partake in activities involving throwing.

Peterson (1998) looked at five Natufian (12,500-10,000 BP) populations from Jordan and Palestine, looking to see whether spear and atlatl use continued into this time, or whether the bow and arrow replaced throwing weapons as the dominant hunting tool. Peterson looked at the same musculoskeletal markers as Kennedy (1983) as well as other upper limb markers. She concluded that MSM, along with humeral cortical thickness, and faunal studies all supported the continued use of throwing technology and that there was no skeletal evidence of use of bows and arrows for hunting.

Molleson and Blondiaux (1994) used MSM and pressure facets to look for evidence of equid riding in Kish, Iraq from various time periods. They examined 15 femurs, looking at the definition of the linea aspera, gluteal muscles, Poirier's facets (iliac impressions), and trochanteric spicules. Of the 15 femurs examined, four show a prominent linea aspera, where the adductor longus muscle attaches (used for gripping and preventing being thrown from the horse). Two of the four (a pair of left and right) also show prominent gluteal tuberosities, but lack femoral heads to view the other traits. The other two have prominent insertion areas of the three gluteal muscles, including trochanteric spicules where the obturator internus attaches, used for lateral rotation of the leg. These two femurs also show Poirier's facet. Poirier's facet is a type of pressure facet, which is generally obtained when there are certain movements that cause the two bones of a joint to rub against each other. The Poirier's facet is created by an extension of the articular surface of the femoral head onto the anterior surface of the femoral neck (Kostick 1963:395). This occurs where the femoral neck touches the acetabulum, due to habitual extension of the hips and knee flexion (Kennedy 1989:147), as can occur while sitting cross-legged or during horseback riding. While one of these traits could explain other activities, the femurs that were examined show multiple traits that point to riding as the underlying

Figure 2.2 - Poirier's facet (modified from Mann and Hunt 2005:166).

cause. The time period of the individuals studied ranged from approximately 2750 BC – 500 BC. The oldest time period here is significant in that there had been no documentation for equestrian activity.

Multiple Usage

Although many of the above authors used musculoskeletal stress markers in multiple ways (Eshed et al. 2004, Havelkova et al. 2011, Lieverse et al. 2009), explaining every way in which each author used MSM in all cases would be more confusing than highlighting how one feature can be examined. However, the integration of uses of MSM in a study is also necessary to understand the complexity of the issue and an example is given below.

Hawkey and Merbs (1995) looked at musculoskeletal stress markers of the upper limbs from Thule Eskimo groups from two time periods, separated by a climatic shift to colder temperatures. An increase in use of *pectoralis major* and *pronator quadratus* was found in later Thule males, consistent with harpooning at a downward angle. Later Thule males showed a decrease in prominence of other MSM that were consistent with kayaking and launching a harpoon. This is consistent with the faunal record, showing an increase in seal remains, which would be killed with a downward thrust of a harpoon. Early Thule males showed prominent markings of the *costoclavicular ligament*, specifically the J shape called “kayakers clavicle”, consistent with kayak use despite lack of archaeological evidence for kayaks. Also examined was the difference between the Early Period Thule males and females, where Hawkey and Merbs found MSM prominence that they believed was consistent with preparation of animal skins for clothing, and rowing a boat.

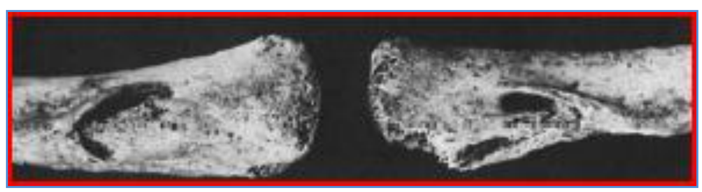

Figure 2.3 - "Kayaker's clavicle" adapted from Hawkey and Merbs (1995:334).

MSM Methods

There is no standard for scoring of MSM (Kennedy 1998:309); however most studies of MSM are qualitative, using various scoring systems to show an increasing amount of development of markers.

There are some studies that will simply note the presence or absence of certain features without ranking them, but they are a minority (Galera and Garralda 1993, al-Oumaoui et al. 2004, Cardoso and Henderson 2010).

The most frequently used qualitative method of scoring is that of Hawkey and Merbs (1995), described earlier. Hawkey and Merbs' method uses a scale of 0-3 for robusticity of markers and a scale of 1-3 for stress lesions. Below is the scoring of the *pectoralis major* insertion on the humerus. A "0" is

Figure 2.4 - Robusticity grades 0-3 of pectoralis major insertion on the humerus (Hawkey and Merbs 1995:327).

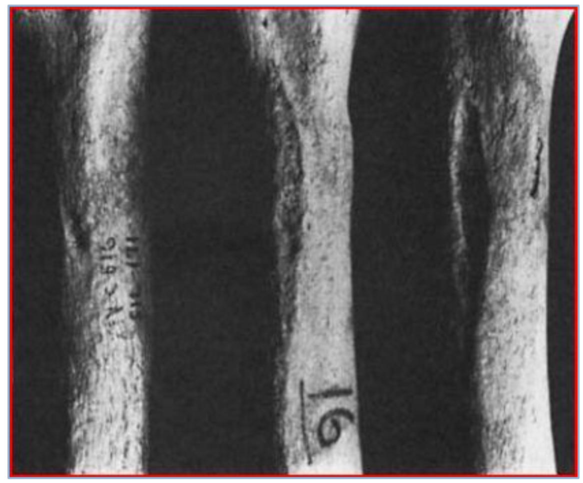

Figure 2.5 - Stress lesion grades 1-3 of pectoralis major insertion on the humerus (Hawkey and Merbs 1995:328).

described as an absence of the feature. For robusticity grade 1, the cortex is slightly rounded, but this is not easily noticeable. Robusticity grade 2 is a noticeable mound and unevenness of the bone cortex. Robusticty grade 3 is the strongest expression with distinct crests of ridges and possibly a sulcus. The stress lesion grades increase based on the size and depth of the lesions, with grade 1 being less than 1 mm deep and grade 3 being more that 3 mm in depth or 5 mm in length. Each MSM is different in its expression and does not get scored the exact same way, but the general principle applies. Most authors using Hawkey and Merbs' system have observed that there is continuity between robusticity grade 3 and stress lesion grade 1, and have combined the two scores into one 0-6 scale (Munson Chapman 1997, Peterson 1998, Steen and Lane 1998, Eshed et al. 2004, Weiss 2004, Lieverse et al. 2009, Niinimaki 2011). Hawkey and Merbs' system also includes scoring for ossification exostoses, kept separate from the others because ossification is thought to be from macrotrauma and not habitual use of the muscle. Hawkey and Merbs' method is popular both because of the number of studies that have used it, allowing a study to be compared to others and because of the low rates of inter- and intra-observer error.

Other authors have come up with their own system of scoring MSM on an ordinal scale (Stirland 1998, Robb 1998, Mariotti et al. 2007). Robb (1998) uses a 1 to 5 scale of robusticity, one having no visible marks and five showing heavy lytic surface damage. Similarly, Stirland (1998) uses a 0-4 ranking system, where 0 signifies no development, 1 is slight development, 2 shows an uneven development of the bone surface, 3 shows further development than 2, and 4 shows extensive bony buildup, sometimes containing lesions. Mariotti et al. (2007: 293-294) began by using the method laid out by Robb (1998) and later reduced the number of categories to 1-3 (the first 3 of Robb's categories were included in the first category), in order to reduce intraobserver and interobserver error. The degree to which one individual will categorize the same feature differently at different times of observation is the intraobserver error. The percentage to which two observers will disagree on the categorization of features is the interobserver error rate. The reduction of categories makes it more likely that there will be agreement on the placement of a feature into one grade of development; however it groups more variation together and may be too simplistic. Mariotti et al. (2007) attempted to keep some of the data on

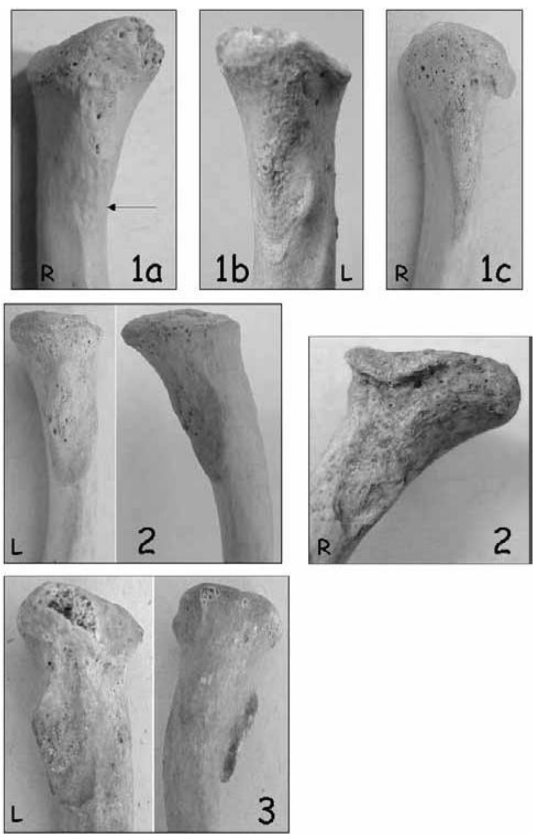

Figure 2.6 - Mariotti et al.'s (2007:303) 1-3 scoring of the *costoclavicular ligament* of the clavicle.

variation with the categorization labels of 1a, 1b, and 1c. Mariotti and co-workers calculated the inter- and intraobserver error with a computer program that compared all the different results to the overall total, and with the reduction of categories the error dropped from 28.1% to around 20%. Even with the reduction of categories, the error rate appears to be high, although Mariotti et al. (2007) considered it to be acceptable.

More recently Havelkova and Villotte have proposed the use of a scoring system that differentiates types of entheses, based on whether they are fibrous or fibrocartilaginous attachments (Havelkova and Villotte 2007). Fibrous attachments are found on the appendicular skeleton where a thick layer of cortical bone occurs. Fibrocartilaginous insertions are found mainly on the epiphysis or apophyses of bones. Villotte and Havelkova use four different scoring systems based on the type of muscle and how MSM presents itself on the point of attachment. Three of the groups include fibrocartilaginous attachments and the fourth includes fibrous attachments. The first group of fibrocartilaginous attachments are those that respond to stress by creating enthesophytes, lesions, foramina, and cysts and are scored based on the contour and surface. The second group consists of fibrocartilaginous attachment sites that respond solely with enthesophytes and are scored based on the size of the enthesophyte. The third group of fibrocartilaginous attachments is that of ligaments on the vertebrae and they are scored metrically. The last group is the fibrous attachments that are scored based on degree of irregularity of the surface. The intra-observer agreement of scoring was high, except in the last two groups. The publication on this method is recent, and has not gained widespread use.

Non-Occupational Factors

Musculoskeletal stress markers on individuals are not solely the result of occupational force exerted on the musculoskeletal system. If this was the case, there would be consistency of the presence and degree of development of stress markers found in one group. A number of other factors need to be considered with the examination and evaluation of musculoskeletal stress markers: sex, body size, and age.

Sex is a difficult factor to discuss with MSM, because by itself it is not a cause of differences in skeletal markers. There is a clear sex difference in the appearance and severity of musculoskeletal stress markers; however, this is likely due to sexual dimorphism or sexual division of labor based on cultural norms (Robb 1998:370). Sex generally becomes a non-significant factor in MSM once body size is accounted for (Niinimaki 2011:296), but this is not true in all cases. Weiss and colleagues argue that sex and size are generally correlated and thus are not easily distinguishable as individual causes (Weiss et al. 2010).

Body size influences MSM, partially because larger bones have more area for muscles to attach themselves and more muscle is required for a larger body to function in the same way as a smaller body (Niinimaki 2011:295). This can account for the larger MSM seen in males, who have larger bodies and thus require more musculature. Body size is controlled not just by use-based bone remodeling, but also by both genetic factors and nutrition. Genetics can control the extent that bone and muscles grow in an individual and malnutrition can stunt that growth so that bones and muscle do not reach their potential size.

Musculoskeletal stress markers do show an age bias. In Jit and Kaur's (1986) study of the costal tuberosity, they found that the earliest evidence of the tuberosity was at four years of age, and the earliest bilateral appearance was at 8 years. Robb (1998) suggests that muscle markings only start to accumulate after bone has finished growing. One of the reasons for this lack of accumulation of MSM is that the bone is still being modeled and the location of muscular attachment on bone is shifting (Hoyte and Enlow 1966:206). However, Capasso and Di Domenicantonio (1998) have found severe lesionous activity of the costal tuberosity in children from Herculaneum, Italy, suggesting that heavy labor in children can impact MSM earlier in life. Once bone finishes growing in length, musculoskeletal stress markers appear with more frequency. As humans age, these musculoskeletal stress markers appear to increase in severity as well (Weiss 2004, Cardoso and Henderson 2010, Molnar 2010, Niinimaki 2011, Havelkova et al. 2011); older individuals (over 35) tend to show more development of the markers than younger adults (under 35), MSM being more robust or more lesionous. This is either due to an increased number of muscular tears with age or a need to strengthen the muscle attachment while the density of bone decreases (Niinimaki 2011:297).

The examples used in this chapter convey the range of uses of MSM in evaluating occupation, socioeconomic status, sexual division of labor and tool use in skeletal remains and how the expression of MSM is affected by age, sex, and size of the individual. I will compare a more objective computerized analysis to the subjective methods used by prior authors in order to determine whether the same results will be achieved and evaluate the usefulness of this new method. This method, along with the collection used in this study will be described in the following chapter.

CHAPTER 3: MATERIALS AND METHODS

Materials

The sample used in this study consists of the clavicles of 69 individuals from the late 19th century Colorado Mental Health Institution at Pueblo. The Colorado Mental Health Institution at Pueblo (CMHIP) skeletal collection consists of approximately 160 individuals that were patients buried on the grounds of the Colorado Insane Asylum during its early years (1879-1898). The Colorado Insane Asylum was renamed the Colorado State Hospital in 1917, and again renamed the Colorado Mental Health Institute at Pueblo in 1991. The cemetery was given the designation 5PE527.6, being within the State Hospital District, and is known as "Cemetery 2" although no other cemetery has been found on the grounds (Collins 1992:2).

The cemetery at the CMHIP was initially excavated in 1992, prior to the building of the San Carlos Correctional Facility, and the remains of approximately 131 individuals were disinterred. With the decision to expand the San Carlos Correctional Facility in 1998, more of the grounds were searched for burials and the remains of approximately 31 individuals were discovered. Most of the remains were found to be primary burials; however, some of the remains excavated in 2000 had been disturbed, likely due to construction and in a couple of cases, multiple individuals were discovered in the same burial pit (Painter 2002).

Asylum Background

The Colorado Insane Asylum was opened in October of 1879, introduced due to the rising population of Colorado and in an effort to eliminate the population of the insane in prisons and reduce costs of caring for patients in eastern institutions. The institution was created on the farmhouse purchased from and grounds donated by George M. Chilcott (Colorado Weekly Chieftain 1879), who became Colorado's United States Senator in 1882. Dr. Pembroke R. Thombs was appointed Superintendent of the hospital and he remained in that position until he resigned in late 1899 after an investigation into misconduct at the asylum. One of the causes for concern during Dr. Thombs tenure as

Superintendent at the asylum was the burial of patients on the asylum grounds (Pueblo Daily Chieftain 1899).

The original purpose of the asylum was to address those cases of insanity that were considered treatable, such as alcoholism. However, over the years more and more individuals with untreatable conditions, such as epilepsy, dementia and those deemed idiots or imbeciles, filled the asylum, creating overcrowding (Colorado Insane Asylum 1896). The patients at the asylum provided the labor to construct new buildings, help build ditches for other improvements to the grounds and were involved in food production for consumption by patients (Colorado Insane Asylum 1884). Patient labor was considered to be a positive activity, allowing the patients to be useful to the community while providing them with exercise and lowering costs of managing the asylum.

Not all patients were able to participate in construction projects because of their mental or physical states. Some would have been physically able but mentally incapable of following instructions. As shown by the admission records from the Colorado Mental Health Institute of Pueblo from 1879-1899, many patients were paralyzed or experienced some difficulty moving due to old age or muscular problems, and had no physical ability to perform labor. One quarter of the patients at the asylum in the years 1879-1899 died at the asylum. Of those that died, exhaustion and impaired movement were the leading causes, followed by age related causes, epilepsy or convulsions, and infectious diseases. The chart below lists the percentage of patients that died of each category. The organ failure category includes heart and brain problems, the infectious diseases include tuberculosis, meningitis, and influenza, and the other category consists of things such as accidents, Bright's disease, and diabetes. Almost one third of those that died during 1879-1899 were buried on the grounds of the asylum.

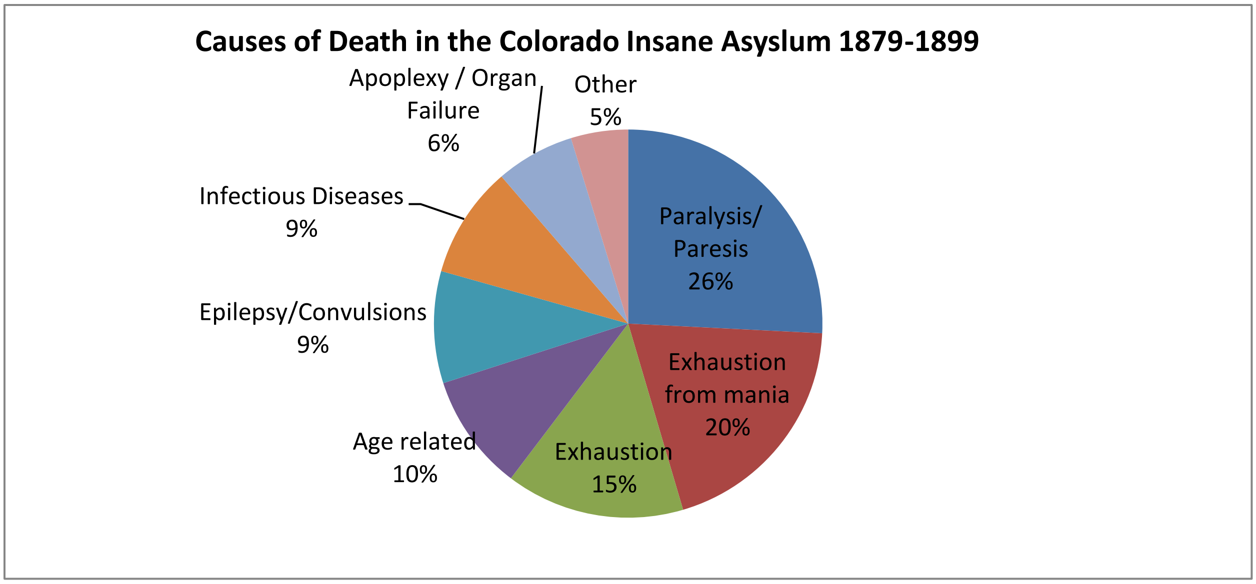

Figure 3.1 – Pie chart showing causes of death at the Colorado Insane Asylum from 1879-1899.

Based on the organization of the burials in rows, it is likely that the graves were marked at one point, but the markings have since disappeared and may have been used for firewood or other purposes. No written record has been found stating which individuals were buried on the grounds of the asylum, so it is not possible to know exactly who is buried in each grave. More research would be required to eliminate individuals by locating graves at other cemeteries in the state. However, it seems most probable that those individuals who had families with no means to bury them, or those with no families at all were buried on the grounds.

Asylum Population

The Colorado Insane Asylum records show that 1,937 individuals were admitted between when the institution opened in 1879 and December 31st, 1899. Of the 1,937 admitted during this time period, approximately 903 either died at the asylum, or there was no record of their discharge. Close to 600 (588) of those individuals died/have no record during 1879-1899, the years in which Cemetery 2 was potentially in use, with approximately 500 having a date of death recorded.

Sex

The population of the asylum showed a heavy male bias, with 72% of patients being male, and only 27% being female. In less than 1% of cases there is no sex listed in the admission records. This same proportion of males and females is seen for the individuals listed as having died at the asylum or having no death or discharge record, of which one with no record is said to have been buried at a local cemetery, suggesting that more of those with no records may have, in fact, died at the asylum and no record was kept. Of those that do have a recorded date of death there is an even higher percentage of males (77%) than females (22%). Considering the large numbers of males in the asylum, it is odd that there are no records of death or discharge for more female patients than males (46 females versus 36 males). The skeletal sample used in this study consists of 47 (68%) males and 22 females (32%), a proportion of each sex that is only slightly different than the medical record indicated.

Age

Age at admission was the sole record taken pertaining to the maturity of the patient, with no birthdates listed. The accuracy of the recorded ages cannot be known. The age at death of the individuals at the Colorado Insane Asylum was determined using the age at admittance and date of death. The results are in Table 3.1 below. The youngest age at admittance was 7 and the oldest 90. These are the youngest and oldest with recorded deaths as well. There are relatively few individuals that died under the age of thirty at the asylum, and it appears that there is an overrepresentation of this

Table 3.1 – Approximate age at death for patients at the Colorado Insane Asylum from 1879-1899 that have age at admission and a date of death recorded.

Approximate Age at Death of Individuals with Recorded Death							
Sex/Age	<20	20-29	30-39	40-49	50+	Unknown	Total
Male	6	31	99	105	141	6	388 (77%)
Female	4	20	32	28	27	0	111 (22%)
Unknown	1	0	1	3	0	1	6 (1%)
Total	11 (2%)	51 (10%)	132 (26%)	136 (27%)	168 (33%)	7 (1%)	505 (100%)

group among the individuals in the CMHIP skeletal collection. It may be that mature adults (30-49) had families that wanted to claim them and could afford a burial and thus the young were more likely to be left at the asylum after death and were buried on the grounds.

Occupation

Occupation as stated in the asylum records relates to the job the person performed for income or subsistence. Occupation is a changeable aspect of life and a category may have been assigned that was the last occupation practiced before admittance to the asylum, or that was practiced the majority of the individual's life. Occupation might not have been known, or it may have been generalized for understanding. Occupations of individuals at the asylum were mainly those of the lower class. People with means would most likely have had a family member cared for at home or at a private institution and not a state run asylum.

The asylum population consisted predominately of unskilled laborers; the males were mostly laborers, farmers and miners while the females were housekeepers or domestic servants. Those that died/had no record of discharge during the relevant period were mainly those of the lower class, with males having more diversity of occupation than females. Of the males that died or had no record of discharge, 26% were laborers (when patients that were discharged are included, 26% of the asylum population were listed as labors), 19% farmers (19% when those discharged are included), 13% miners (15% when discharged are included) and 6% had no occupation (6% including the discharged). Many were skilled laborers of various occupations, such as blacksmiths, carpenters, coopers, and cabinetmakers. Figure 3.2 on the next page shows the breakdown of male occupations for those listed as deceased or with no discharge record present in the asylum between 1879 and 1899.

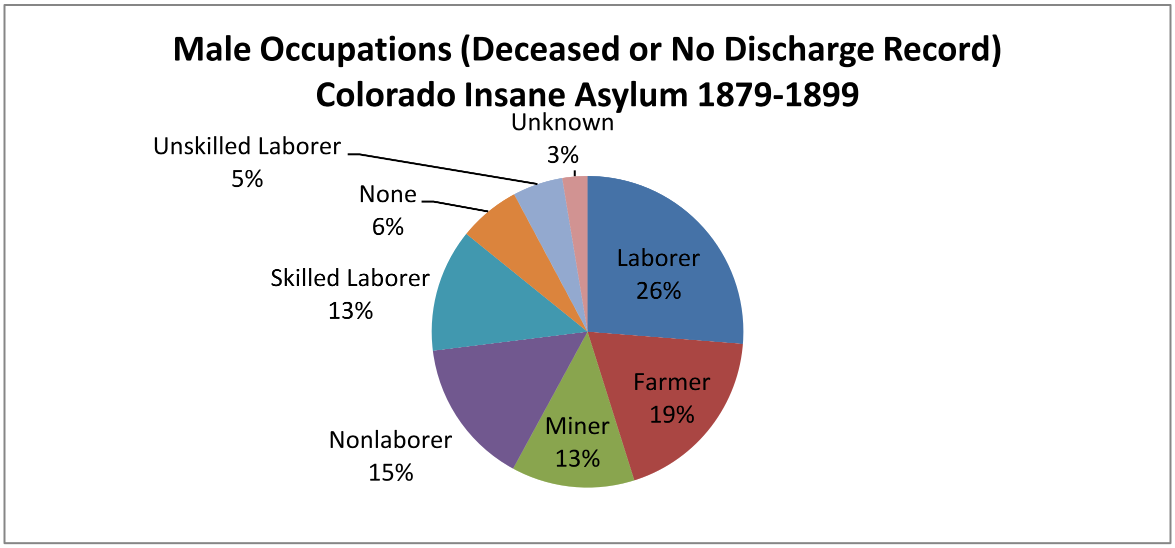

Figure 3.2 – Pie chart of occupations for males that have a recorded death or no discharge record from the Colorado Insane Asylum from 1879-1899.

Of the females that died at the asylum or have no discharge record, 66% were housekeepers, servants, or domestics (almost 73% in entire asylum population when those discharged are included), and 25% had no occupation (18% when those discharged are included), 4% were teachers (2% when the discharged are included), 2% had unknown occupations, 1% were seamstresses and less than 1% were laundresses and midwives. Figure 3.3 below shows the breakdown of female occupations of those deceased or have no record of discharge from 1879 to 1899. This population of laborers is important to keep in mind when looking at the musculoskeletal stress markers present on the bones in the CMHIP collection.

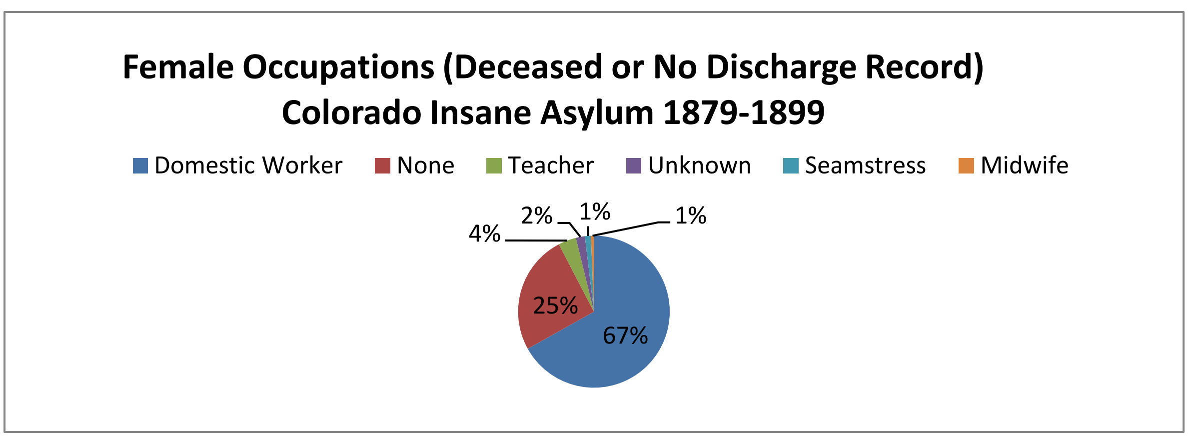

Figure 3.3 – Pie chart of occupations for females that have a recorded death or no discharge record from the Colorado Insane Asylum from 1879-1899.

Methods

This study examines musculoskeletal stress markers in 69 individuals from the CMHIP collection. The 69 individuals were chosen based on the presence of both clavicles and minimal damage to areas of muscular and ligament attachment. Only adults were selected, due to the late fusion of the sternal epiphysis of the clavicle, the increased development of musculoskeletal stress markers with age and the rarity of subadults in the collection. Ageing was done via pubic symphysis morphology, and sexing was based on cranial and os coxae characteristics (Buikstra and Ubelaker 1994, Bass 2005). If necessary, measurements of femoral and humeral head diameter or femoral mid-shaft circumference were used to estimate sex (Buikstra and Ubelaker 1994, Bass 2005). Ages were put into ten year intervals (20-29, 30-39, 40-49, 50+).

Table 3.2 – Approximate age at death for sample split into four age group categories and separated by sex.

Age at Death					
Sex/Age	20-29	30-39	40-49	50+	Total
Male	6	15	10	16	47 (68%)
Female	7	8	4	3	22 (32%)
Total	13 (19%)	23 (33%)	14 (20%)	19 (28%)	69 (100%)

Clavicle

The clavicle was the focus of this study due to its small size and the importance of the bone in shoulder movement. The clavicle acts as a go-between from the axial skeleton to the appendicular skeleton, specifically the upper limbs. The clavicle connects the sternum to the scapula and acts as a stabilizing force for the shoulder, restricting movement and preventing dislocation. Because of its function in regard to the shoulder, the clavicle has many muscle and ligament attachments that are often times quite prominent and that generally have discernible borders. This is quite useful in a study on musculoskeletal stress markers.

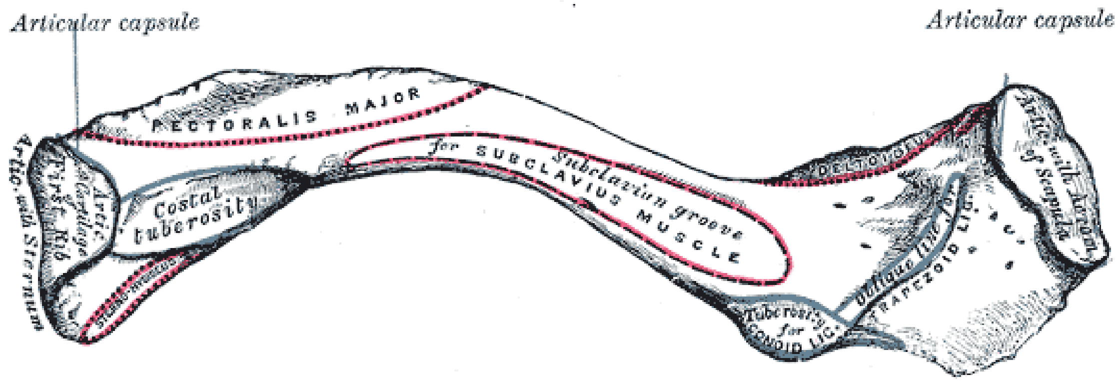

Figure 3.4 - Muscle and ligament attachments on the posterior surface of the clavicle from Gray's Anatomy (1974:136).

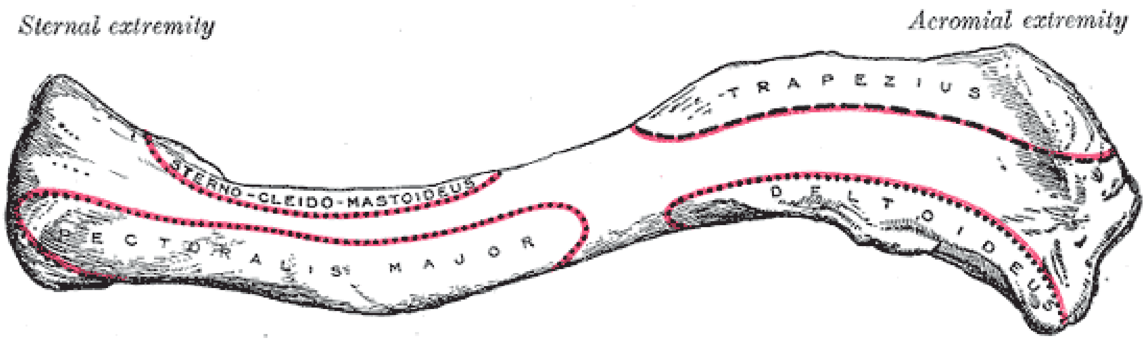

Figure 3.5 - Muscle and ligament attachments on the anterior surface of the clavicle from Gray's Anatomy (1974:136).

The clavicle is a unique bone; its shape is singular in the curvature present, it has a special function due to its positioning in the body and it is the shortest long bone. The clavicle is also one of the few long bones, and the only upper limb long bone that generally shows a left lateralized length asymmetry, meaning that the left clavicle is generally longer than the right, although the right is usually more robust. One of the possible explanations for this is mechanical in origin; that the need to have more movement in the dominant arm (usually the right) would create the need for a shorter clavicle (Mays et al. 1999:27). This differential use can create a strong degree of asymmetry. Table 3.3 shows the muscles and ligaments that attach to the clavicle and their respective functions (Galera and Garralda 1993; Hawkey and Merbs 1995; Munson Chapman 1997).

Table 3.3 – Muscles and ligaments that attach to the clavicle, their location of attachment on the clavicle, movements associated with the muscles and ligaments and activities that have been associated with those movements (Galera and Garralda 1993; Hawkey and Merbs 1995; Munson Chapman 1997).

Muscle/Ligament:	Location:	Movement:	Suggested Activities:
Deltoid Muscle	anterolateral surface	flexion and medial rotation of arm	using slingstone weapons, kayaking, maize grinding (Munson Chapman 1997)
Costoclavicular Ligament	costal tuberosity / medial end	stabilizes the sternoclavicular joint	plowing, stone-house building, hanging weights from shoulders, sailors working and repairing sails, positioning bronze cannons, use of longbows, kayaking (Hawkey and Merbs 1995)
Pectoralis Major Muscle	anteromedial	arm flexion; adduct and medially rotate the arm	using slingstone weapons, kayaking
Trapezius Muscle	posterolateral	elevation and upward rotation of the scapula	chopping wood
Subclavius Muscle	subclavian sulcus	depresses the shoulder, down and forward clavicular motion	no associated activities published
Trapezoid Ligament	oblique ridge	stabilizes acromioclavicular joint	assists conoid ligament and trapezius muscle
Conoid Ligament	conoid tuberosity	use of the arm above 90 degrees in flexion or abduction, helps stabilize acromioclavicular joint	chopping wood, carrying burdens on the shoulders and/or upper back (Munson Chapman 1997)
Sternocleidomastoid Muscle	anteromedial	flexing and rotating the neck	chronically flexed position

Scoring Musculoskeletal Stress Markers

Scoring musculoskeletal stress markers is the most common method used in order to study activity patterns in human skeletal remains as described earlier. The *costoclavicular ligament* attachment site on the clavicle was the feature chosen for this study because it has the most visually obvious variation present on the clavicle. The scoring of the costoclavicular ligament attachment site, or costal tuberosity, is based on a 1 to 6 ordinal scaling, similar to Hawkey and Merbs (1995). A score of 1 shows slight development of the costal tuberosity, although the area is not clearly defined. A score of 2 has a clearly defined raised area. A score of 3 has a depression of the tuberosity. Those scored as 4 show a more warped tuberosity, with lipping and more porous bone. A score of 5 has a large lesion near the sternal end of the tuberosity. Those with a score of 6 have large amounts of pitting in the tuberosity. Those that showed enthesopathies, pathological bone growth on the costal tuberosity, were scored as NR, or non recordable. Each of the 138 (69 left and 69 right) clavicles used in this study was scored based on these criteria, first by being placed in order of development of the *costoclavicular ligament* attachment site and then being given a specific score. In addition to the scoring, measurements were taken for maximum length and midlength superior-inferior diameter and midlength posterior-anterior diameter in order to control for size of the individual.

3D digitizing procedure

Figure 3.6 – Example of setup, showing MicroScribe and clavicle in locking pliers attached to vise.

Both the left and right clavicles of all individuals within the sample were scanned using a 3D digitizing MicroScribe (Immersion Corporation). This device records a series of 3D coordinates in order to create a 3D image of an object. The MicroScribe G (Immersion Corporation) was used with the default tip (Length to point .5" (12.7 mm), Delta offset 0" (0 mm)). The clavicles were placed in locking pliers attached to a vise so that they did not need to be moved to scan relevant locations as seen in Figure 3.6. This method does lead to an absence of data where the pliers hold the clavicle. However, the pliers were placed so that the areas where measurements were needed were not obscured. Three attachment sites were used in this study: that of the *costoclavicular ligament*, the *pectoralis major muscle*, and the *deltoideus muscle*. The muscle/ligament attachments were each scanned individually, with 14 points taken for the costoclavicular ligament attachment site, 12 taken

Figure 3.7 – *costoclavicular ligament* point order.

for the *pectoralis major*, and 14 for the *deltoideus muscle* attachment site. The point order is shown in Figures 3.7-3.9, with the first point being taken on the site of attachment closest to the sternal end of the clavicle and then proceeding clockwise, with points in the center of the feature being taken last.

Figure 3.8 - *Pectoralis major* attachment site point order.

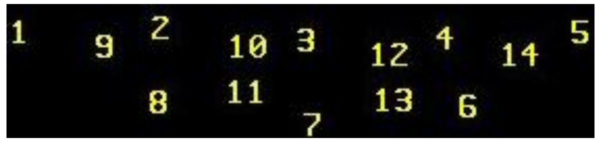

Figure 3.9 - *Deltoideus muscle* attachment site point order.

Statistics

After data collection, a Generalized Procrustes analysis (GPA) was run using Morphologika[2] (O'Higgins and Jones 1998) and MorphoJ (Klingenberg 2011). GPA seeks to take all of the shapes and remove as much difference as possible that is caused by size, rotation, and location. Objects are uniformly scaled, rotated and translated and a mean shape is obtained through superimposing all shapes. This procedure also allows right and left clavicles to be analyzed together, because one side is mirrored in order to look like the other.

All data that had the Generalized Procrustes analysis performed in Morphologika[2] had the new Procrustes coordinates entered into PAST (Hammer et al. 2001), along with age and sex data. A two group multivariate test was performed to determine whether males and females in the sample have the same average shape for each of the features. A non-parametric MANOVA was performed to determine whether age groups have the same average shape; this included both an overall analysis of age groups, and individual comparisons between age groups. Euclidean distance measure was used in both the two group multivariate tests and in the non-parametric MANOVA tests (Hammer and Harper 2006:118).

The coordinate data from the MicroScribe was also imported into MorphoJ, along with the corresponding sex and age data. A Generalized Procrustes analysis was performed and then a discriminant function analysis, using a Procrustes distance measure, was performed to determine whether the mean shape of males and the mean shape of females is the same. This analysis was also used to compare age groups; however, comparisons were made only between specific age groups. There was no overall age group comparison. Along with giving a probability that two groups have the same mean shape, the discriminant function analysis gives a graphic representation of the differences in mean shape between the groups being compared.

All statistics that were based on MicroScribe data were non-parametric or permutational, due to the Generalized Procrustes analysis performed on the data collected. After Procrustes superimposition, the number of free variables exceeds the number of degrees of freedom (Webster and Sheets 2010:174). Parametric tests assume a certain number of degrees of freedom based on the number of variables, but when a Procrustes analysis is done, there are fewer degrees of freedom so non-parametric statistical tests are necessary. Non-parametric, or permutational tests are less powerful than parametric tests and are also more conservative. With non-parametric tests, it is necessary to run the test multiple times and then take an average of the results, because you get a different result each time the test is run. For this study, each non-parametric test was run one hundred times and the average probability is given for groups having the same mean shape. Each test run has α equaling .05; test results greater than .05 are not considered statistically significantly different. This means that any groups less than .05 have a significantly different mean shape and those above can be said to have the same mean shape. The results for both the traditional scoring and the 3D digitizing are explored in the next chapter.

CHAPTER 4: RESULTS

Costal Tuberosity Scoring Results

The traditional method of scoring musculoskeletal stress markers is based on the rugosity of the feature, with a higher score given to those with pitting or with more abnormal features. The scoring system used in this study was a scale ranging from one through six, judged based on the descriptions given in Table 4.1. Although size is not considered a criterion in the scoring of the costal tuberosity, it does play a part. Individuals with larger attachment sites for the *costoclavicular ligament* are more likely to have higher scores, this is in part due to use creating a larger attachment site and in part due to bias, because it is easier to see any abnormality of shape on a costal tuberosity that is larger.

Table 4.1 – Scoring key for the costal tuberosity.

Scoring Key:	
1	Area not clearly defined
2	Raised area, but mostly flat surface
3	Indentation
4	Warping, lipped, becoming porous
5	Large pit near sternal end
6	Large amount of pitting

In this population there are many individuals with a high degree of rugosity, as seen by the scoring of the costal tuberosity. Table 4.2 summarizes the total number of clavicles that were included in each score category. Each bone analyzed was categorized for the side (left or right), sex (male or female), and age (categorized 1-4). As seen in Table 4.2, the most common result in this sample was a score of 3, and the least common was a score of 1. Those categorized as NR were not recordable, either because of damage or a large enthesophyte. A total of 138 bones were analyzed, from 69 individuals (47 males and 22 females).

Table 4.2 – Count of male and female clavicles that fell under each score classification for the costal tuberosity.

Score Count (All)							
	1	2	3	4	5	6	NR
Male	3	8	24	19	19	19	2
Female	1	8	19	8	3	4	1
All	4	16	43	27	22	23	3

Side

The lefts and rights show different scoring patterns, with the left side having overall lower scores than the right side. Table 4.3 shows the difference between the right and left side in the number of individual bones assigned to each score. The right side had no bones scored as 1, and had more individuals scored with a 4, 5, or 6 than the left side did. The average score for the left side was 3.59, and for the right side 4.13. The difference in score is likely due to use difference, with some individuals engaged in more manual labor involving mostly their dominant arm, which in most cases is the right arm.

Table 4.3 – Count of male and female clavicles that fell under each scoring category of the costal tuberosity, separated by side of bone.

Score Count (Left)								Score Count (Right)							
	1	2	3	4	5	6	NR		1	2	3	4	5	6	NR
Male	3	6	12	9	8	8	1	Male	0	2	12	10	11	11	1
Female	1	5	10	3	2	1	0	Female	0	3	9	5	1	3	1
All	4	11	22	12	10	9	1	All	0	5	21	15	12	14	2

Sex

Females, in general have lower scores than males, with very few showing pitting on the costal tuberosity. The average score of all costal tuberosities analyzed (not including the non recordable), was 3.9, however, females had an average of 3.4. Despite this lower average, females are present in each categorical expression of rugosity in the costal tuberosity, with 7 female clavicles having a score of 5 or 6. Although sample size plays a part in the overall lower numbers shown by females, it is still rarer for females to have higher rugosity scores on average than males. However, in the average of the age 3 category, females and males have a very similar score, but this may be due to the small samples size. In general, females are less rugose than males, likely due to a sexual division in labor that is less demanding on females as well as the hormonal differences that cause males to be on average, larger and more muscular than females. Table 4.4, below shows the average score of males and females for both left and right sides, along with the average score for each age category.

Table 4.4 – Average score of costal tuberosity as separated by sex and age group.

Average Costal Tuberosity Scoring (All)					
	Age 1 (20-29)	Age 2 (30-39)	Age 3 (40-49)	Age 4 (50+)	All
Male	4.4	4.0	4.3	3.9	4.1
Female	3.1	3.1	4.3	3.6	3.4
All	3.6	3.7	4.3	3.9	3.9

Age

Table 4.5 – Average costal tuberosity score of males and females, separated by age group on the left clavicle.

Average Costal Tuberosity Scoring (Left Side)					
	Age 1 (20-29)	Age 2 (30-39)	Age 3 (40-49)	Age 4 (50+)	All
Male	4	3.9	4.1	3.4	3.8
Female	2.7	2.9	3.8	4	3.1
All	3.3	3.6	4	3.5	3.6

Table 4.6 – Average costal tuberosity score of males and females, separated by age group on the right clavicle.

Average Costal Tuberosity Scoring (Right Side)					
	Age 1 (20-29)	Age 2 (30-39)	Age 3 (40-49)	Age 4 (50+)	All
Male	4.7	4.1	4.6	4.4	4.4
Female	3.4	3.4	4.8	3	3.6
All	4	3.8	4.6	4.3	4.1

There is a general trend toward increasing score with age, as seen by the average scores. However, the scoring results are not suggestive of a continuation of increasing rugosity with age, but that after age 50 there is a decrease is robusticity on the costal tuberosity on both the left and right side. This may be due to the inability to continue heavy labor after the age or 50, due to difficulty moving either because of age or paralysis.

Conclusion

The advantage of using the more traditional scoring method is that it is easier to compare populations. Although scoring is subjective and each individual will score a musculoskeletal stress marker differently, it is possible through pictures and descriptions to have consistent scoring between individuals and between studies. This sample came from a population consisting mostly of laborers, accounting for the large numbers of lesions present on the costal tuberosity, as seen through the amount of scores that were 5 or 6. Males and females both used their right arm in labor more often or with a greater intensity than their left. Males and females were both engaged in labor, although most females were involved in less intensive household labor. The age results are less clear, possibly due to sample size, but the data suggest that the oldest group of individuals had participated in less heavy labor in their final years, possibly due to age or paralysis.

3D Digitizing Results

The 3D digitizing MicroScribe was used to look at three musculoskeletal stress markers on the clavicle: the costal tuberosity, and the attachment sites of the *pectoralis major muscle* and *deltoideus muscle*. The statistical tests performed are comparing the average shape of two or more groups and determining whether they are from the same population, meaning whether they are different or the same.

Sex Differences

One of the main questions this study seeks to answer is whether males and females are different in regard to musculoskeletal stress markers. Whereas the traditional scoring method leaves size in as a factor, the use of a generalized Procrustes analysis lets size be taken out of the equation. This is useful in male-female comparisons, because in general males have larger bones and correspondingly large muscles and thus larger muscle attachment sites than females. When using a scoring based on visualization, it is easy to bias your scoring decision based on the size of the feature.

Costoclavicular ligament

The comparison of mean shape between males and females on the attachment site of the *costoclavicular ligament* (costal tuberosity), shows an overall difference between males and females. The results of the two-group multivariate permutation are shown in Table 4.7 below, and were similar in significance to the Procrustes distance results from MorphoJ. We can see that on the right side, males and females have a different mean shape; however, on the left side there is no statistically significant difference in shape between males and females at α=.05. This is similar to the results from the traditional scoring, where males and females show more difference on the right side than on the left. Again, this is likely due to a sexual division of labor, males engaging in heavy labor where they used their dominant arm.

Table 4.7 – Probability that males and females have the same mean shape of the attachment site of the *costoclavicular ligament*.

Costoclavicular ligament	All	Left	Right
Permutations:	9999	9999	9999
PAST p(same mean):	0.0068	**0.0797**	0.0004
MorphoJ p(same mean):	0.0075	**0.0708**	0.0003

Males and females have a significantly different shape on the right costal tuberosity of the clavicle and when the left and the right sides are analyzed together, but it is important to know how males and females are different. The figures below show how each landmark shifts when going from the female to male mean shape. The left and right sides together and the right side by itself are represented, both from two vantage points. The difference we see between the left and right together versus the right side by itself is a matter of extremes; landmarks that shift when the left and right sides are analyzed together move to a greater degree when just the right side is represented, as would be expected from the overall shape change representing an average between a non-significance in mean shape from the left side and a very significant difference in mean shape from the right side. The sternal end of the feature is at landmark 1 and the acromial end is located at landmark 5. Axis 1 and 2 in these instances are representing the length and width of the feature. The change from female to male mean shape appears to have to do with the width of the costal tuberosity, as seen by the extension of

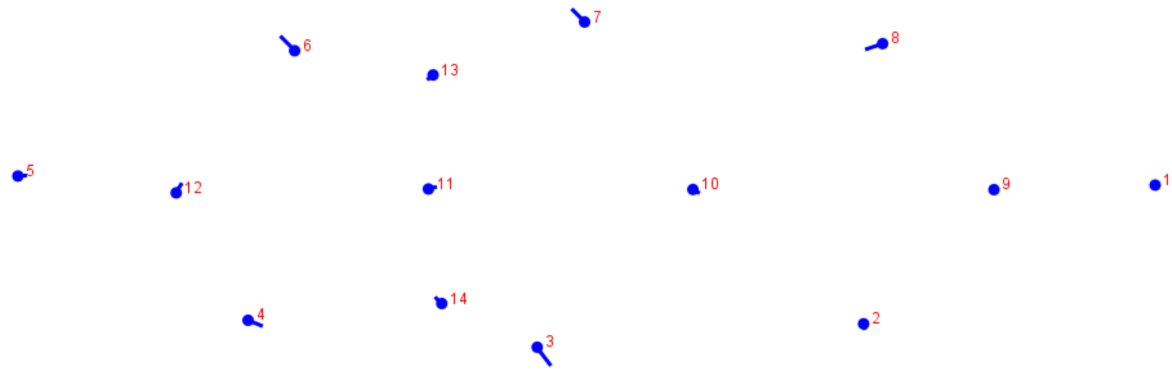

Figure 4.1 - Costal tuberosity left and right, direction of change from female to male mean axis 1 and 2.

landmarks 3 and 7 away from the other landmarks. There is also a narrowing near the sternal end in the mean male shape, as seen by landmark 8 moving toward the center. Figures 4.2 and 4.4, showing axis 1 and 3 give an idea as to how depth is changing from the female to male mean shape. The most apparent shift in depth is in landmark 10, but landmarks 9 and 11 also shift in the same direction to the male mean while landmarks 1 and 5 go in the opposite direction, creating an overall deeper costal tuberosity in males.

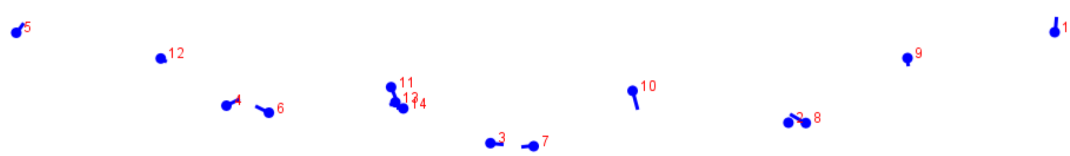

Figure 4.2 - Costal tuberosity left and right, direction of change from female to male axis 1 and 3.

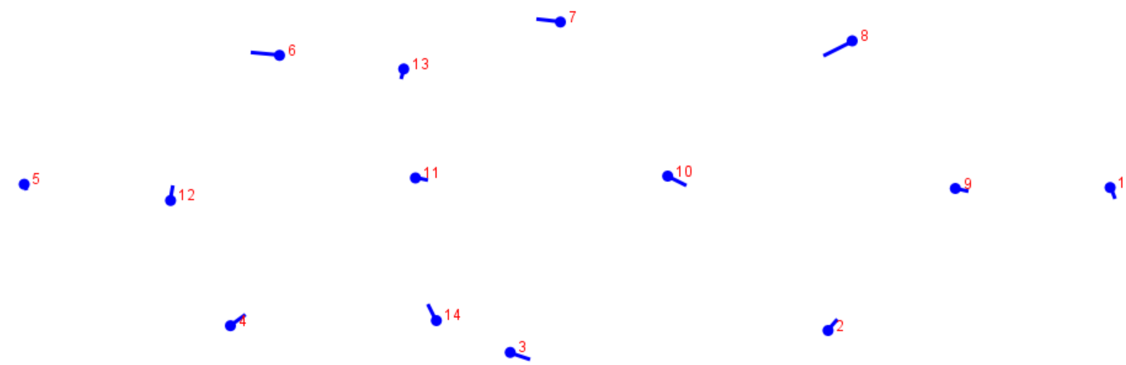

Figure 4.3 - Costal tuberosity right side, direction of change from female to male mean axis 1 and 2.

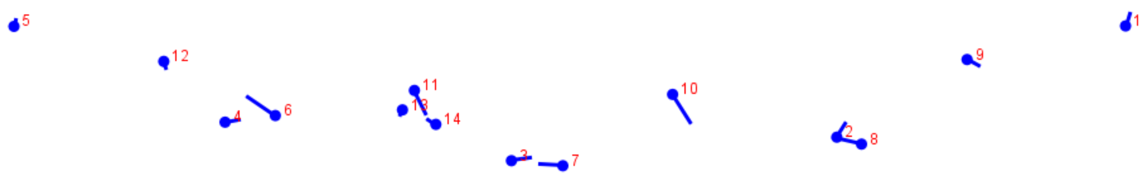

Figure 4.4 - Costal tuberosity right side, direction of change from female to male mean axis 1 and 3.

Pectoralis major muscle

The mean shape difference between males and females for the site of attachment of the *pectoralis major* matches that of the costal tuberosity, with the overall shape and the right side being significantly different. Unlike with the costal tuberosity, however, the left side does not come close to significance, as is seen in Table 4.8. Similar results were achieved in MorphoJ, with the left side not showing significant difference between males and females, suggesting a similar pattern of usage. Again, this speaks to the heavier use of the right arm by males, due to labor requiring the use of the dominant arm.

Table 4.8 – Probability of males and females having the same mean shape of the *pectoralis major*.

Pectoralis major	All	Left	Right
Permutations:	9999	9999	9999
PAST p(same mean):	0.001121	0.402452	0.0001
MorphoJ p(same mean):	0.001015	0.399628	<.0001

Like the costal tuberosity, the attachment site of the *pectoralis major* varies the most from the female mean shape to the male mean shape on the right clavicle; the left and right shape difference is merely more extreme for the right side alone. As seen in Figures 4.6 and 4.8 below, the male mean shape shows more surface depth variation than the female mean shape, especially on the right clavicle. The shape from female to male also appears to be shifting in one direction on the inferior surface and the opposite direction on the superior surface. Based on the way the *pectoralis major muscle* attaches to the clavicle, this is most likely the direction the muscle was being pulled during use.

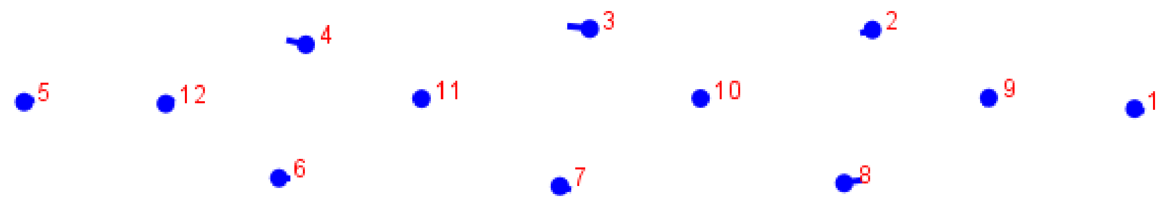

Figure 4.5 - Left and right *pectoralis major* attachment site, direction of change from female to male mean on axis 1 and 3.

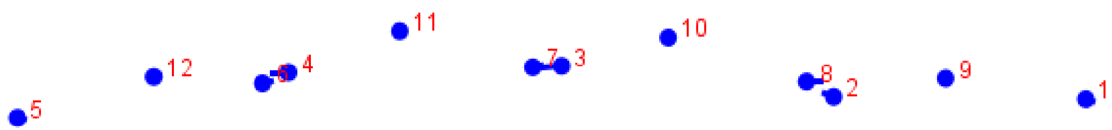

Figure 4.6 - Left and right *pectoralis major* attachment site, direction of change from female to male mean on axis 1 and 2.

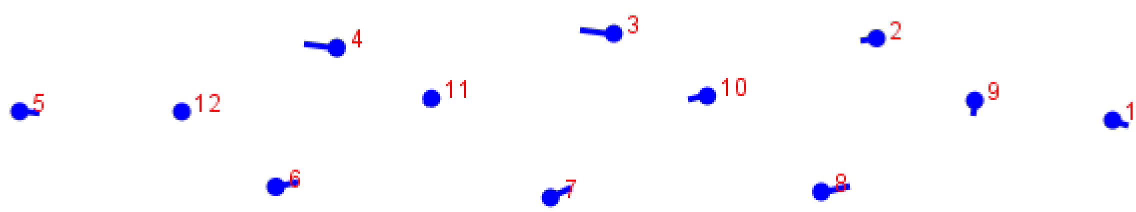

Figure 4.7 - Right *pectoralis major* attachment site, direction of change from female to male mean on axis 1 and 3.

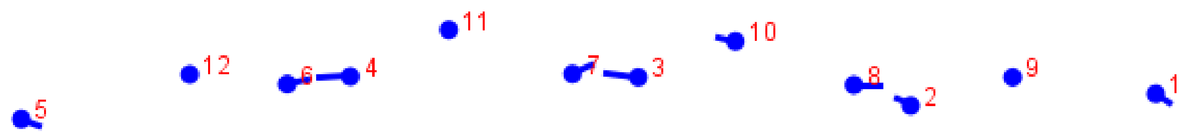

Figure 4.8 - Right *pectoralis major* attachment site, direction of change from female to male average on axis 1 and 2.

Deltoideus muscle

Males and females have an overall similar mean when lefts and rights are analyzed together for the *deltoideus muscle* attachment site. When each side is analyzed separately, males and females show a significantly different mean shape as seen in Table 4.9. The reason for the combined left and right results showing the same mean is likely due to the problem of reflection discussed earlier. A similar test, using permutational discriminant function run in MorphoJ, using Procrustes distance instead of Euclidean distance shows there is a statistically significant difference between the male mean and the female mean shape when the left and right sides were analyzed together at a $p < .0001$. Again, as seen in the *pectoralis major muscle* attachment site, it appears that the direction of the change is due to pull on the muscle; we can see that in landmarks 7 and 8 going in different directions on the left sites versus the right.

Table 4.9 – Two group permutation probability that males and females have same mean shape.

Deltoideus	All	Left	Right
Permutations:	9999	9999	9999
PAST p(same mean):	0.265523	0.005762	0.000101
MorphoJ p(same mean):	<.0001	0.005267	<.0001

The *deltoideus muscle* differs from the *costoclavicular ligament* in that males and females differ on both the left and right side. This could be the difference between males being involved in activities that strongly influence one side of the body and females being involved in activities that influence both. The difference on the left side could also be due to the complex shape of the *deltoideus* compared to the elliptical shapes of the costal tuberosity and the *pectoralis major*. Removing size during Procrustes superimposition of the *deltoideus muscle* attachment site may cause male shapes to be warped, because of the more complex shape.

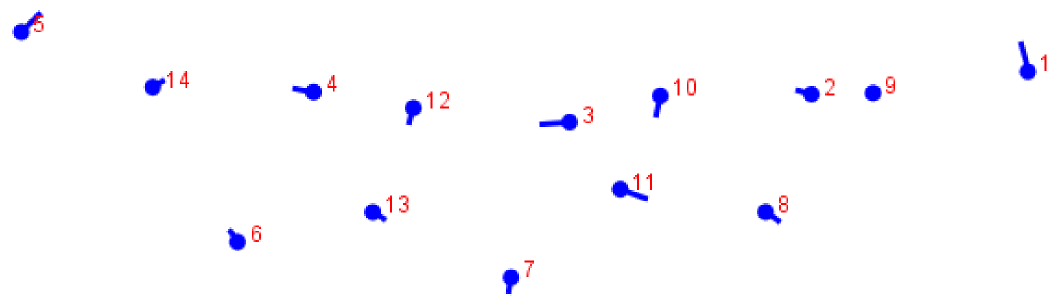

Figure 4.9 - Left and right *deltoideus muscle* attachment, direction of change from female to male mean on axis 1 and 2.

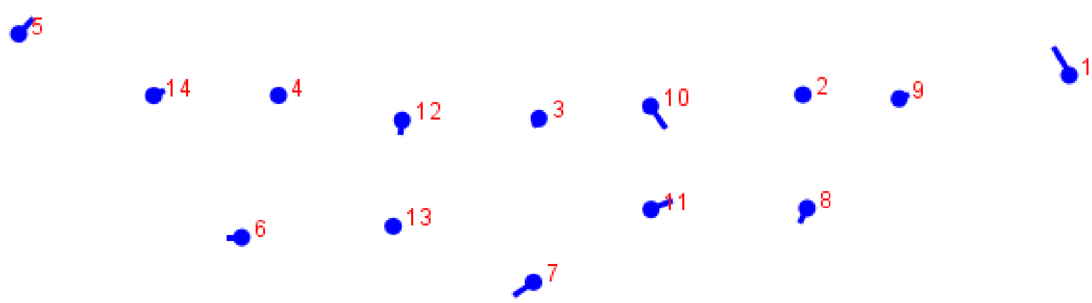

Figure 4.10 - Left *deltoideus muscle* attachment, direction of change from female to male mean on axis 1 and 2.

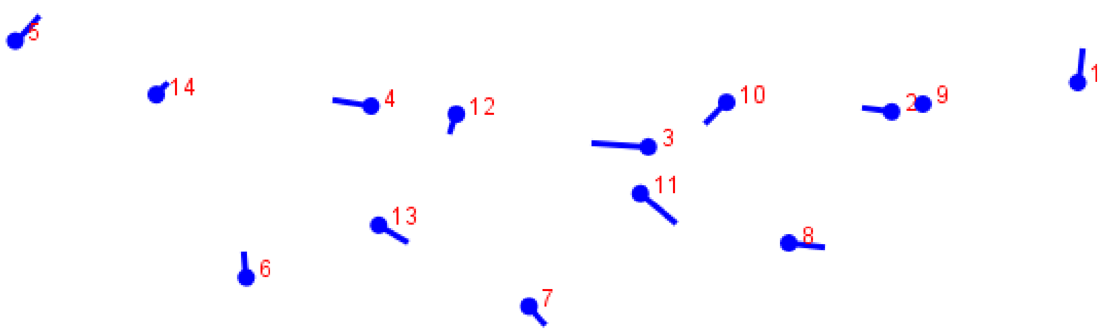

Figure 4.11 - Right *deltoideus muscle* attachment, direction of change from female to male mean on axis 1 and 2.

Conclusion

The *pectoralis major muscle* and the *deltoideus muscle* work together in many motions, such as arm flexion and medial rotation of the arm. These movements are important for lifting and motions similar to bailing hay or the downward swing when using an axe, and one would expect them to have similar patterns of change due to this shared responsibility. However, the *deltoideus muscle* attachment site on the clavicle shows that the male and female mean shape is different on both the left and the right side, whereas the *pectoralis major* only shows male-female differences on the right side. The *pectoralis major muscle* takes part in adduction of the shoulder and the *deltoideus muscle* is part of the opposite motion, or abduction of the shoulder (Calais-Germain 2007:135). We might conclude from this that males are doing some activity with their right arm that involves adduction of the shoulder, such as pulling, or that activities are affecting males more on the right *pectoralis major muscle* or affecting the left side less than what is seen on the *deltoideus muscle*.

Age Results

Another question this study seeks to answer is whether analyzing musculoskeletal stress markers as 3D data points there is a visible shape difference with regard to age groupings. Ages were categorized 1-4, as shown in Table 4.10. Age groups were analyzed for overall difference using a nonparametric multivariate analysis of variance (MANOVA) using a Euclidean distance measure in PAST and a permutational discriminant function analysis using Procrustes distance in MorphoJ. These analyses express whether the age group categories had statistically different shapes, but do not allow for the ordinal scope of the data.

Table 4.10 – Key for age range representation for each age group.

Age Group	Age Range
1	20-29
2	30-39
3	40-49
4	50+

Unlike comparing sexes, where males are on average larger than females, size is less of a factor in looking at age. However, the complexities of how musculoskeletal stress markers respond with age makes comparing age groups much more complicated than when comparing males and females. Age is also more difficult to assign than sex, partially due to the increase in categories from two sexes to over one hundred different ages and the amount of variation present that can obscure assignment of age. For example, although the ages at which teeth come in are pretty tightly genetically controlled, there is still variation as to when those teeth will come in for each individual. This makes age assignment more difficult to put a specific number to and is why an age range is used in this study.

Costoclavicular ligament

The *costoclavicular ligament* attachment site (costal tuberosity) shows an overall difference between age groups only on the right clavicle. The left side shows no overall difference between age groups as well as no difference between any two age groups. The left and right sides analyzed together also show no overall significance for age groups when a nonparametric MANOVA was performed as seen in Table 4.11; however, when comparing only two age groups 1 and 4 are almost statistically significant at α=.05 and are statistically significant at α=.1. Similar results were achieved using MorphoJ as seen in Table 4.12, which is the basis for the following figures. The difference between the mean shape of age group 1 and age group 4 are shown below. On the

Table 4.11 - NPMANOVA probability of different mean shape between age groups for the costal tuberosity using Euclidean distance measure.

Costoclavicular ligament (PAST)	Overall	1--2	1--3	1--4	2--3	2--4	3--4
ALL p(same mean):	0.3634	0.3166	0.2316	**0.0517**	0.6175	0.7479	0.5011
LEFT p(same mean):	0.6783	0.4572	0.4164	0.6937	0.5245	0.5648	0.6711
RIGHT p(same mean):	0.0205	0.2015	0.4219	0.0094	0.1885	**0.075**	0.0431

Table 4.12 – Discriminant function analysis probability of age groups having the same mean shape using Procrustes distance.

Costoclavicular ligament (MorphoJ)	1--2	1--3	1--4	2--3	2--4	3--4
ALL p(same mean):	0.3127	0.229	**0.0918**	0.6155	0.8676	0.6116
LEFT p(same mean):	0.452	0.4129	0.8199	0.5292	0.5725	0.7364
RIGHT p(same mean):	0.2012	0.4234	0.0092	0.1865	**0.0743**	0.0425

right clavicle, the mean shape of age group 1 is significantly different from group 4, and groups 3 and 4 are also significantly different. Group 2 is not significantly different from group 4 at α=.05, but is significant at α=.1 (.0743). Figures 4.12 and 4.13 below show the directions in which the mean shape changes between group 1 and group 4, and Figure 4.14 shows the direction of change between group 3 and group 4. These images show that overall there is more change between group 1 and group 4 than from group 3 to group 4, which we would expect. Again, this supports the idea that males were primarily using their dominant arm in labor.

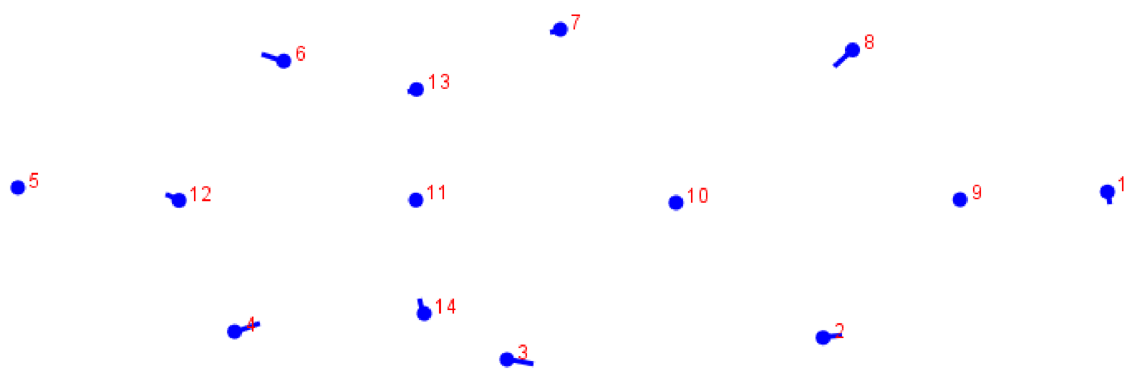

Figure 4.12 - Costal tuberosity left and right, direction of change from age group 1 (20-29) mean shape to age group 4 (50+) mean shape on axis 1 and 2.

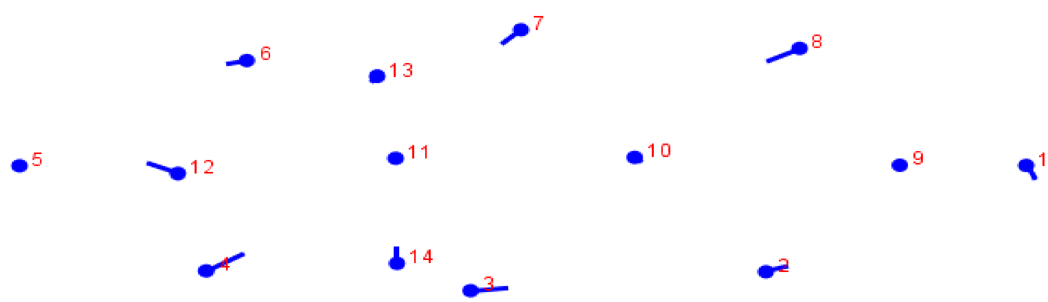

Figure 4.13 – Costal tuberosity right direction of difference between mean shape of age group 1 and age group 4 on axis 1 and 2.

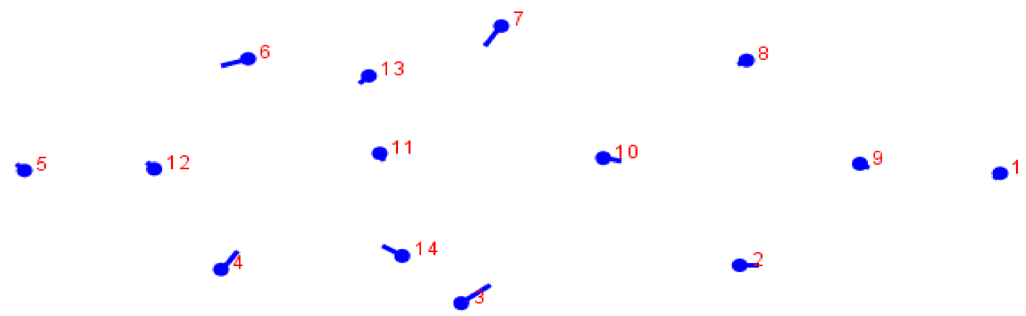

Figure 4.14 - Costal tuberosity right direction of difference between age group 3 and age group 4 mean on axis 1 and 2.

Pectoralis major muscle

The attachment site of the *pectoralis major muscle* on the clavicle showed vastly different results when comparing age groups as opposed to sex. Instead of the right side showing a significant difference overall in means, the left side does. However, when explored further, we find that when lefts and rights are combined for analysis, the mean shape for age group 1 is statistically significantly different from all other age groups. When the left side is analyzed by itself, the mean shape of age

Table 4.13 - NPMANOVA probability of age groups having the same mean for *pectoralis major* attachment on the clavicle.

Pectoralis major muscle (PAST)	Overall	1--2	1--3	1--4	2--3	2--4	3--4
ALL p(same mean):	0.0089	0.0127	0.0002	0.0059	0.1779	0.9936	0.6548
LEFT p(same mean):	0.01738	**0.08203**	0.004	0.0083	0.1227	0.7995	0.2288
RIGHT p(same mean):	0.3047	**0.0928**	0.0064	0.1226	0.4577	1	0.8067

group 1 is statistically significantly different from both age groups 3 and 4. However, when the right side is analyzed by itself and all groups are compared individually, age groups 1 and 3 differ in mean shape. The difference between age group 1 and 3 on the left and right sides can be seen in Figures 4.15 and 4.16 below and the corresponding MorphoJ probabilities are in Table 4.14. Although this feature is the

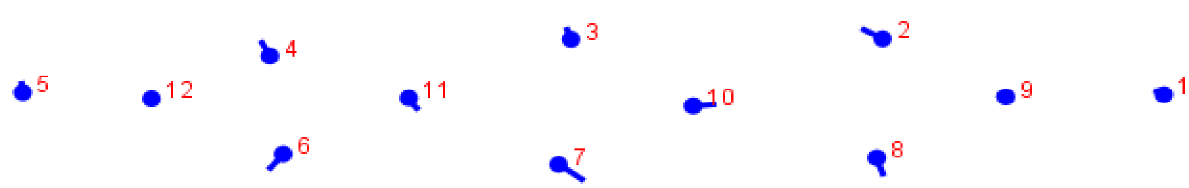

Figure 4.15 – Left *pectoralis major muscle* attachment site direction of change from mean shape of age group 1 to age group 3.

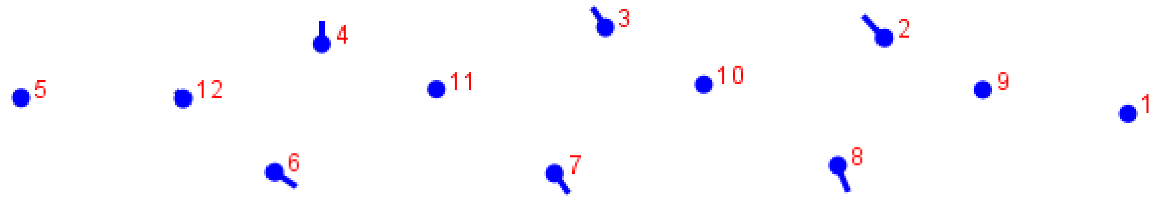

Figure 4.16 – Right *pectoralis major muscle* attachment site, direction of change from mean shape of age group 1 to age group 3.

only one that overall is different on the left side and not on the right side, the specific differences suggest that there is some age related change occurring on both the left and right muscle attachment sites.

Table 4.14 - Probability of age groups having the same mean shape of the *pectoralis major* attachment site from MorphoJ.

Pectoralis major muscle (MorphoJ)	1--2	1--3	1--4	2--3	2--4	3--4
ALL p(same mean):	0.0125	0.0002	0.0057	0.18	0.9935	0.6494
LEFT p(same mean):	**0.0817**	0.0039	0.0081	0.1215	0.8001	0.2284
RIGHT p(same mean):	**0.093**	0.0062	0.1212	0.461	1	0.8045

Deltoideus muscle

The *deltoideus muscle* attachment site on the clavicle shows no statistically significant difference overall between age groups on the left and right sides both when analyzed together and when analyzed separately as seen in Table 4.15 below. When age groups are compared individually, no groups are

Table 4.15 – NPMANOVA Probability of age groups having the same mean shape for the *deltoideus muscle* attachment site on the clavicle.

Deltoideus muscle (PAST)	Overall	1--2	1--3	1--4	2--3	2--4	3--4
ALL p(same mean):	0.2958	0.1656	0.6663	0.1549	0.1855	0.4699	0.7056
LEFT p(same mean):	0.9023	0.6063	0.952	0.5946	0.6354	0.756	0.8805
RIGHT p(same mean):	0.1084	**0.089**	0.352	**0.0674**	0.1407	0.3528	0.4479

significantly different from each other on the left side. On the right side, age groups 1 and 2 and age groups 1 and 4 are statistically significantly different at α=.1 but not at α=.05. It appears that for the *deltoideus muscle* attachment site, age is less of a factor in shape variation, but that it still plays a role;

the most notable difference being between age groups 1 and 4 on the right side supports this, because it represents the extremes, seen in Figure 4.17 below.

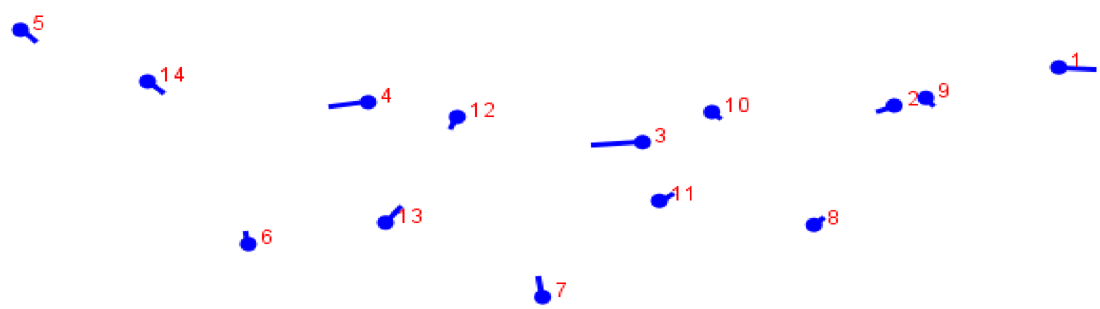

Figure 4.17 - Right *deltoideus muscle* attachment site, direction of difference between shape of age group 1 mean and age group 4 mean on axis 1 and 2.

Table 4.16 – Probability of age groups having the same mean shape from MorphoJ.

Deltoideus muscle (MorphoJ)	1--2	1--3	1--4	2--3	2--4	3--4
ALL p(same mean):	0.1736	0.6844	0.1618	0.1866	0.469	0.7069
LEFT p(same mean):	0.6032	0.9519	0.5979	0.6347	0.7555	0.8823
RIGHT p(same mean):	**0.093**	0.3601	**0.0694**	0.1404	0.3485	0.4432

Conclusion

The analysis of difference between male and female musculoskeletal stress markers is less complicated than that of age group analysis. This is likely due to the increase in number of categories and the complexities of musculoskeletal stress marker changes with age and the distinct differences seen in males in regards to overall body size and muscular development compared to females. However, there does appear to be a correlation between shape and age group, although in most cases the difference is only statistically significant between the extreme age ranges and mostly on the right side. Age group 1 is statistically significantly different from at least one other age group for each feature at α=.1 on the right clavicle and is statistically significantly different at α=.05 for the attachment site of the *costoclavicular ligament* and *pectoralis major muscle*. On the left clavicle, only the *pectoralis major muscle* attachment site shows statistically significant differences between age groups. This again supports the idea that men were predominately using their right arm in labor, likely due to being right-handed, causing changes in their musculoskeletal stress markers as they age.

CHAPTER 5: CONCLUSION

With the availability of more sophisticated equipment for measuring and analyzing, it is tempting to disregard older, simpler methods. However, these newer, high tech methods require expensive equipment, complex procedures and statistical know-how that more traditional methods lack. This study has compared two methods of looking at musculoskeletal stress markers using 138 clavicles from the Colorado Mental Health Institution at Pueblo collection. A comparison was made between the more traditional method of giving an attachment site a score based on robusticity and a method involving the use of a 3D digitizer with geometric morphometric software, in order to investigate the usefulness of a 3D digitizer for this kind of analysis. To do this, the advantages and disadvantages of each method will be analyzed based on their ability to answer relevant questions as well as the procedures involved.

This study sought to answer whether the traditional scoring method or the 3D digitizing method shows a difference between males and females, whether age groups vary using either method, to determine what each method is showing, and which method is more useful. The hypothesis was that, when controlling for size, males and females would show fewer differences. This is an important distinction between the two methods, because 3D digitizing allows size to be controlled for through use of a general Procrustes analysis. For both methods, males and females are different on muscle attachment sites of the right clavicles that were examined. However, while the scoring method shows differences on the left side of the *costoclavicular ligament* attachment, the digital method does not always show sex differences on the left side, as made clear by *pectoralis major*. The costoclavicular ligament did not show significant results at $\alpha=.05$ on the left side, but did so at $\alpha=.1$, suggesting that there is likely a difference between males and females on the left side, but it is less dramatic than the difference exposed on the right *costoclavicular ligament* attachment site of the clavicle. The scoring method does show greater male-female differences on the right side than on the left. The scoring method, along with the digitizing method confirms a sexual division of labor where males were favoring their dominant, or right arm, over the left. Age was predicted to be an important indicator in musculoskeletal stress marker variation because of previous studies showing accrual of muscle with age (Jit and Kaur 1986, Robb 1998). In both methods, age shows less clear differences than that of sex, with the traditional scoring method showing age group 3 (40-49) having the highest average score and with the statistical analysis from the digitizing method showing only overall (when all four age groups are analyzed together) significant differences on the right side between age groups on the costoclavicular ligament attachment site, but not on either *pectoralis major* or *deltoideus* attachment sites. However, there is in both methods evidence of gradual change in musculoskeletal stress markers with age. When analyzing whether two or more groups show similarity or differences, it is clear that both methods are qualified to answer and that neither method is clearer than the other.

The strength of the 3D digitizing method is that categorization is not based on prior assumptions as to how musculoskeletal stress markers are formed. However, interpreting the results with regards to degree of labor performed is also less clear. The traditional method is not reliant on complex data collection with expensive equipment, various computer software or complex statistical processes. This makes the traditional method less time consuming in both collecting data and analyzing results. It also means that this method has a shorter learning curve; so that anyone with some training can perform an analysis of musculoskeletal stress markers. Although, when comparing two groups, the traditional method gives a clear numeric value showing that one group is more developed than another, it is however, difficult to determine as a group where the differences are. The 3D digitizing method allows direction of change to be seen from one group to another without defining what that difference means; so the difference is not necessarily about robusticity as seen in the traditional scoring method.

The results from the scoring method allow us to say that this group of people was engaged in heavy labor throughout their lives. Because the 3D digitizing method was only used in within-group analysis of the remains in the Colorado Mental Health Institute at Pueblo collection, it cannot establish whether or not those analyzed were engaged in heavy labor. To establish that using the 3D digitizing method alone, it would first require analysis of other collections with known degrees of labor. However, in concert with the scoring method, we can say that the population was highly laborious and that after size is controlled for, males are still more robust than females. The complicated results in regard to age using both methods is reassuring in that neither method shows a clear transition in either shape or robusticity with age, suggesting that maybe a different categorization of ages is necessary or that the accrual of musculoskeletal stress markers with age is too complicated to expect specific age group to have corresponding scores or shapes. It might not be possible to see clear age categorization in this collection due to the paradox of having both a population primarily composed of laborers and at the same time a great many of those died due to paralysis or paresis.

More research is needed in order to determine the range of utility for the 3D digitizing method. Although for the moment the traditional method of analyzing musculoskeletal stress markers is more feasible, the 3D digitizer shows great potential for a more in depth exploration of group differences. Along with using this method on other collections, an attempt should be made to discover the optimum number of points that should be collected for each musculoskeletal stress marker in order to encapsulate areas of variation. More musculoskeletal stress markers should be scored for comparison between scoring and 3D digitizing analysis. As stated above, age categorization is problematic, and an attempt should be made to determine whether different categories, such as ages 20-40 and 40+ or 5 year age categories, instead of the 10 year categories, will produce more clear results. It would also be beneficial to be able to analyze age data on a ratio or ordinal scale as opposed to a nominal one; allowing for gradual age group change to be seen in ways other than comparing only two age categories at a time. The promise of what musculoskeletal stress markers can tell us about the labor level of populations, sexual division of labor, and how accrual of musculoskeletal stress markers with age makes using 3D digitizers, morphometric geometric software, and statistical analysis an encouraging avenue of research.

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