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Etiology of the Stenotic Intercondylar Notch: A Clinical Issue Investigated From an Anthropological Perspective

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Etiology of the Stenotic Intercondylar Notch: A Clinical Issue Investigated From an Anthropological Perspective

A Dissertation submitted in partial satisfaction
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by

Brianna Elise Herndon

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ACKNOWLEDGEMENTS

This dissertation would not have been possible without the wonderful, supportive community of my friends, family, and advisor. First, I would like to thank my parents for being some of my biggest supporters. I do not know if I would have made it here without them. Growing up, my family had dinner together every night, and my parents would ask us what we learned at school. No matter what you answered (it could be "the Earth is round"), my dad would play devil's advocate and argue the opposite. The point of this, sometimes frustrating, exercise was to determine if I had actually learned, or if I had just *memorized* something. Perhaps this is where my distrust of authority and healthy skeptical nature began. Regardless, it was having to answer these difficult questions that really taught me to think for myself, rather than believe something simply because someone with a title told me it was true. I think that one of the primary reasons I am achieving a doctoral degree is because I am passionate about asking questions and interrogating dominant epistemological regimes.

I also laud my parents' restraint in never trying to shape me to be anyone but myself. I had a hard time figuring out what I wanted to do when I was growing up. In grade school, we had to take a test about our interests, and based on these responses, an occupation we might enjoy was suggested to us. What did the internet say would be in my future? It proudly proclaimed that I should be a bricklayer (as a backup, it also suggested stuntperson). I knew absolutely nothing about bricklaying, detested laborious work, and hated touching particular materials with my bare hands. Despite all this, I ran home to tell my parents that I wanted to be a bricklayer, and shortly thereafter, I received

a bricklaying kit from them as a present (I never completed the project). Clearly, I forewent that avenue of work, but I think it is worth noting that never once do I recall my parents trying to deter me from that future. Moreover, they worked hard to quell any doubt I had in my own potential. Countless nights I sat at the dining room table, sobbing over my math homework because “girls can’t do math.” It turns out, I am highly food motivated and can learn math just fine when M&Ms are involved. Years later, I would call home crying about my undergraduate physics course to be greeted days later by the delivery of a family-sized M&M bag.

My mom likes to argue heartily that nature contributes much more than nurture in the outcome of individuals, but I know that I am in academia today because of the environment in which I was raised. My parents were never put off by my interest in postmortem processes. They did not treat me any different when I interned in a coroner’s office and discussed the details of flesh removal by beetles with them. Every time I showed any interest in a subject or field, they would present me with books or activites about those things. However, I really think that the best thing about my parents is that they never let me forget how proud of me they are. I truly believe I would be someone in someplace entirely different if it had not been these two humans who raised me.

I move now to acknowledge the roles of my husband and advisor, two people I never would have guessed I would mention in the same sentence. But without the support of either one of these individuals, I do not think I would be putting the finishing touches on this dissertation today. Graduate school is not for the weak. It is hard to come up with your own research questions, strong methods to test them, and interpret the results to create something meaningful. I have been in academia since I was 17, so the classes were the easy part getting here. It was the imposter syndrome, the crashed computers, and the asymmetrical work-life balance that was the difficult part. I do not know how many times I talked to my husband about dropping out of graduate school, and how many times he talked me into staying. When I met my advisor, Dr. Elizabeth Berger, I was on the precipice of leaving the academy. At the time, I had a project in a state of semi-disarray, with questions I was interested in, but not a strong idea of how to go about answering them. It is a difficult thing to step into the middle of an ongoing project in a geographical region outside your specialty, and help construct something cohesive, but she did. Dr. Berger's empathy, her ability to give constructive criticism in kind fashion, and just the sheer amount of time she has dedicated to my project (and me) have been crucial not only to the production of this dissertation, but in teaching me how to be a better academic and mentor. I cannot thank her enough for allowing me to be her student and mentee.

While Dr. Berger helped me develop academically, my husband held down the fort at home. I have worked two jobs most of my tenure in graduate school, but that means I spend a lot of time away from home. He really shouldered more than his fair load of cooking, cleaning, and balancing my high-strung demeanor with his go-with-the-flow outlook. Right after we purchased our very first house, I had to leave to perform the data collection phase of this dissertation and he moved everything on his own. I could not have gotten a fraction of my academic work completed without his strong support at home.

Finally, I would like to thank the National Science Foundation, UC Riverside funding sources, Iowa's Office of the State Archaeologist (specifically Dr. Lara Noldner), my short-term assistant Danielle DeLangis, and my undergraduate advisor Dr. James Watson who handed me the beginnings of this project. There are so many people who have contributed to who I am about to become – Dr. Herndon – and I think that is a beautiful thing for which I am eternally grateful.

DEDICATION

This dissertation is dedicated to my trusty hounds, Meeko and Goldy, who have never complained about listening to my practice presentations or my proofreading papers aloud.

Oh, also, I dedicate this dissertation to my parents and husband.

ABSTRACT OF THE DISSERTATION

Etiology of the Stenotic Intercondylar Notch: A Clinical Issue Investigated From an Anthropological Perspective

by

Brianna Elise Herndon

Doctor of Philosophy, Graduate Program in Anthropology
University of California, Riverside, June 2024
Dr. Elizabeth Berger, Chairperson

This research reorients a clinical question regarding the relationship between overly narrow femoral intercondylar notches and anterior cruciate ligament (ACL) injury within an anthropological perspective. I argue that biomedical research tends to assume that the dimensions of the notch are only related to genetics or previous ACL rupture. This view, while intended to help determine risk factors for narrow notch development, is a biologically deterministic one that ignores how differential access to resources and opportunities shape individuals' life experiences and health outcomes. To address this shortcoming, I shift the question from a medical perspective – which groups are most likely to suffer narrow notches and therefore ACL injury? – to an anthropological one: to what degree do genetics, metabolic stress, and mechanical factors influence femoral intercondylar notch morphology, and what is the importance of the historical socioeconomic context on these factors? To answer this question, I analyzed historically documented remains from the mid-19th to mid-20th century Santa Clara Valley and use

the osteological data to draw conclusions about assigned racial categories, the construction of Whiteness in this region, lived experiences, and their relationship to morphological outcomes at the knee joint.

The six most important findings from this research are presented as an enumerated list in the concluding chapter, and consist of the following: (1) notch width index and notch volume are not redundant measures and do quantify the notch in noticeably different ways, (2) experiences of metabolic stress, particularly those resulting in porotic hyperostosis, are positively correlated with notch volume, (3) notch volume is not linked to femoral rousticity or shaft shape, (4) notch volume scales with body size, (5) genetics do not seem to significantly influence notch volume, and (6) osteological results support that the category of whiteness in California and the Santa Clara Valley was enlarged compared to other regions of the U.S. during this time period.

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Chapter 1: Bone Biology, Anatomy of the Knee Joint, and Biomedical Precedent

1.1 INTRODUCTION

This dissertation is interdisciplinary – it pulls from the fields of biomedicine, anthropology, American history, sociology, and ethnic studies. As a result, there is a significant amount of groundwork that needs to be laid to understand the importance of this research and the relevance of the research methods chosen. For ease of understanding, I have decided to include two background chapters. The first will delve into the biological and biomechanical background, while the second will be oriented with a more humanistic direction, covering historical (population) background and the theoretical lenses through which I view this research. The division of these chapters is in no way an indication that the biology and the theory can exist apart from one another. Rather, in the results and the analysis section I will argue the exact opposite – that it is an impossibility to examine one without consideration of the other. Instead, I am choosing to think thematically and, in some ways, chronologically, as it was the initial biomedical literature review that first inspired my interest in the developmental outcomes of the femur during my undergraduate studies.

In this first background chapter, I begin by defining the knee joint. This includes an overview of the osteological components, as well as the soft tissue factors with an added focus on the anterior cruciate ligament (ACL), and the basic functions of the knee in a mobile person. The purpose of this basic biological overview is to establish what the biomedical literature considers a “normal” knee and what they may disregard as pathological. I contrast this with my own sample selection, which includes knee joints with pathological features, such as osteoarthritis, because this does affect both mobility and patterns of biomechanical strain. I then cover the basics of bone development and what exactly it is about bone biology that gives these elements capacity for "plasticity," or the ability to reshape/remodel bone in response to various inputs even after osteological maturity (full growth plate fusion) has been achieved. This background is necessary to understand the strengths and weaknesses of Wolff's Law of bone functional adaptation. I conclude this section by presenting a number of studies that indicate the incredible plastic capacity of the femur and help explain high degrees of variability in this bone.

In the next section, I address the question of why the femoral intercondylar notch deserves specific attention. To answer this, I cover previous biomedical research and findings, as well as identify specific weaknesses that I believe my dissertation may offer a way to resolve. In the final section of this chapter, I present three specific hypotheses to be tested, the logic behind them, and briefly how they will be tested. I also acknowledge the high likelihood that the variables tested interact and demonstrate interdependence. All hypotheses are designed to determine the degree to which each variable contributes to the development of a stenotic intercondylar notch, in the hopes of achieving a better understanding of its etiology.

1.2 BIOLOGY OF THE KNEE JOINT

Osteological Components

The knee joint is comprised of three osteological elements: the distal femur, the proximal tibia, and the patella. The knee joint can primarily be visualized as a hinge that produces "flexion between the articular surfaces of the femoral condyles and tibial plateaus" (Meyer and Haut, 2012: 4). The knee is also a diarthrodial joint, which means that it has a layer of fibrocartilage separating the interacting epiphyses and synovial fluid that works like WD-40 to increase the ease of flexion. These anatomical features provide cushion from mechanical forces and promote easy transfer of energy between bone and muscle. The knee, like all other joints, must typically perform a few core functions. Most importantly, the osteological elements comprising the knee must be able to perform some degree of bone remodeling, which can be either stochastic (resorption followed by bone deposition happening consistently throughout the body as biological maintenance) or targeted, such as when trauma or abnormal activity disrupt bone homeostasis (Allen and Burr, 2014). Similarly, to maintain typical bone health, the osteological elements of the knee must maintain a balance between cortical and cancellous bone development to prevent becoming overly heavy or weak (Burr and Akkus, 2014).

Both anthropological and biomedical literature emphasize that this joint must have the capacity to withstand and adapt to long-term mechanical forces, such as compression, without succumbing to fatigue failure from repetitive loading (Cullinane and Einhorn, 2002). To accomplish this, the lower limb demonstrates a high capacity for elasticity and plasticity. The elastic capacity of this bony joint reflects its ability to respond to stress on a short-term scale, with no long-lasting changes to morphology (Cullinane and Einhorn, 2002). In contrast, a plastic response will result in permanent deformation of the bone shape and often occurs after an initial change in the body's biomechanics has been maintained for a period of time or number of loading cycles (Cullinane and Einhorn, 2002). For instance, if one's gait changes due to an injury (e.g., introduction of a limp), then this sustained change in gait loading forces will have permanent osteological consequences. Plastic response of the bony knee joint can result in "bone drift," or a reorientation of the cortex in relation to its central axis (Allen and Burr, 2004).

Variation in distal femur morphology does exist and is mainly attributable to sexual dimorphism (e.g., Stevens and Strand Vidarsdottir, 2008; Yan et al., 2014). However, large variations in shape are generally prevented by the "requirement of uniaxial movement during the stance phase" of bipedal locomotion (Frelat et al., 2017: 157). In other words, due to the primary functionality of the knee as a hinge joint, most movement occurs along the parasagittal axis, and this places constraint on morphological variation (Frelat et al., 2017). Notably, the bicondylar angle seems to be an exception to this "rule" of relatively limited macro-level variation in the knee joint. Adult humans typically have a pronounced bicondylar angle. However, it is important to note that although the "normal" human knee has this bicondylar angle, babies are not born with it and it will typically not develop (or develop minimally) in nonmobile persons, as the forces of bipedal locomotion are the impetus for its formation (Tardieu, 2010). A typical adult bicondylar angle falls somewhere between 8 and 12 degrees, and females generally cluster at the higher end of this range due to “greater interacetabular distances and shorter femora” (Lovejoy, 2007: 334; Waxenbaum and Stock, 2016). For the same reason, females also demonstrate a higher degree of femoral anteversion on average (Tardieu, 2010). For comparison, quadrupedal primates tend to have no bicondylar angle at all (Lovejoy, 2007). Given that development of the bicondylar angle is heavily dependent on mechanical input, population-specific angles may arise due to occupation or other habitual activity types (Waxenbaum and Stock, 2016).

Another hallmark of the typical human knee joint is the ability to achieve a stable, locked position when (hyper)extended. The “locking” of the joint occurs when, during extension, the medial rotation of the femur places the femoral condyles in greatest contact with the tibial condyles (Aiello and Dean, 1990). The medial rotation of the femur happens because the medial femoral condyle is typically taller in height than its lateral counterpart by about 1 centimeter, likely reflecting allometric scaling concerns (Aiello and Dean, 1990: 490). The bicondylar angle that results from differences in condylar heights also causes the quadriceps muscles to create lateral tension on the patella and a risk of displacement (Aiello and Dean, 1990). Although the patella has been addressed very little throughout this dissertation due to its non-loadbearing function, morphologically, a typical adult patella is circular or elliptical with some room for minor variation (Aiello and Dean, 1990). Additionally, the diameter of the patella seems to be a little over half the epicondylar distance of the femur (Aiello and Dean, 1990: 484).

To conclude this section, although there are many ways that a knee must look and function to be considered “normal,” most literature limits its definition to knees that have not experienced surgery or chronic knee pain (in living peoples), and has no obvious pathology or trauma (in living and deceased individuals) (Bremner-Smith et al., 2004; Yan et al., 2014). Sometimes, even typical occurrences such as the age-related development of osteoarthritis at the knee (occurs more frequently in females than males over 45 years of age) is enough for it to be considered "pathological" in the literature (Stevens and Strand Vidarsdottir, 2008). It is worth noting that such subjective definitions allow for differential interpretations of "normal" between researchers. This dissertation does not exclude any individuals whose knees might be considered "pathological" or "abnormal" precisely because it is interested in the etiology of abnormality. Why is it that some individuals have atypically large or restricted notches? What factors contribute to this range of variation, including the extreme ends of the spectrum?

Soft-Tissue Components

There are two primary cartilaginous sections within the articular region of the knee joint. Articular cartilage lines the surfaces of the distal femur that would otherwise come into direct contact with the patella and tibia. Similarly, the meniscus is a

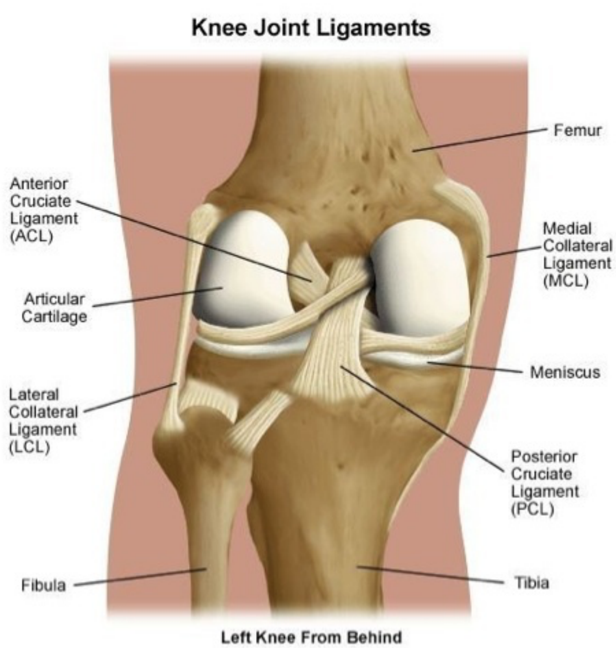


Figure 1.1. *The angled orientation of the anterior cruciate ligament places it at risk of impingement against the lateral notch wall. Image sourced from the Stanford Health Center.*

cartilaginous cushion that sits atop the proximal tibia and has circular depressions in the center that are shaped to fit the femoral articular cartilage (Fig. 1.1). The articular cartilage and the meniscus function together to help the bones of the knee joint articulate tightly and absorb the shock generated by the mechanical forces of activity and movement. It is common, however, for abnormal gait mechanics or unusual activity involvement to disrupt the homeostasis of the cartilaginous tissue and cause thinning, which can prompt pathological developments such as osteoarthritis (Andriacchi, Koo, and Scanlan, 2009).

Aside from cartilage, many tendons, ligaments, and muscles work together to stabilize the knee. Knee stabilization includes allowing flexion, extension, and rotation without malalignment which may be caused by a laxity of tendons and ligaments surrounding the joint. The four main ligaments involved in stabilization are the lateral collateral ligament (LCL), the medial collateral ligament (MCL), the posterior cruciate ligament (PCL), and the anterior cruciate ligament (ACL) (Fig. 1.1). The primary roles of the ACL include preventing an anterior shift of the tibia during flexion and resisting internal tibial rotation caused by the activation of the MCL (Meyer and Haut, 2012). The ACL is located centrally in the knee joint,

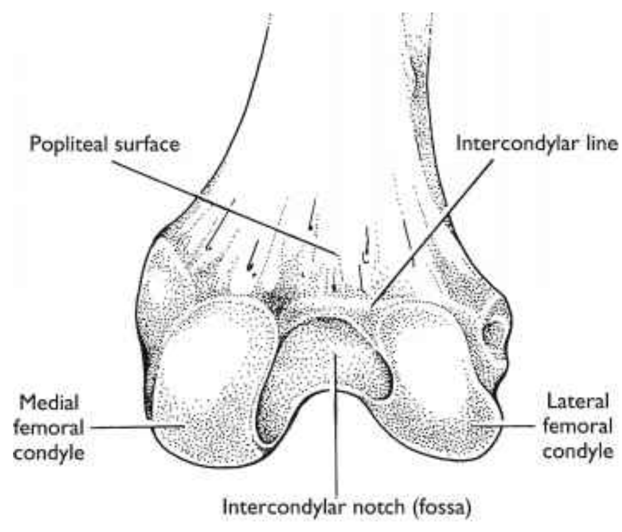


Figure 1.2. *View of the posterior distal femur indicating the anatomical location of the intercondylar fossa. Image sourced from Forensic Medicine of the Lower Extremity, edited by Rich et al. (2005).*

occupying part of the femoral intercondylar fossa (or notch; Fig. 1.2). Its location necessitates a twisting of its fibers between femoral and tibial attachments to provide both pliability and support to the knee (Lovejoy, 2007). Due to its location, the ACL is at high risk for impingement against the lateral notch wall, especially if the space is stenotic, or narrower than average (Hoteya et al., 2011; Shultz et al., 2012). When the ACL fails at higher rates of loading, most commonly the ligament itself ruptures. However, at lower loading rates, avulsion fractures are more likely. Post-ACL rupture, most patients develop osteoarthritis within 10 years (Meyer and Haut, 2012).

Although this dissertation does not explicitly examine the ACL or other soft tissue elements as these are not preserved in the UISC skeletal collection, it is important to understand how these pieces function with the osteological elements to shape knee mobility, morphology, and injury risk. Particularly, the intercondylar notch and the ACL are intimately connected. The smaller that notch space, the more likely that the ACL will be harmed during action. The larger the notch space, the more protected an individual is from this type of injury. Having a large intercondylar notch is especially important given that the aging process presents two additional challenges to the protection of the ACL. First, osteoarthritis (OA) often presents as lipping which can increase in severity to result in osteophytes or bone spurs penetrating the notch space. OA can also develop in younger individuals, depending on the degree and type of localized strain. Second, the intercondylar fossa seems to exhibit some narrowing naturally over the life course (Hirtler et al., 2016). Both aforementioned byproducts of aging place the ACL at higher risk for injury. Thus, while this is an osteological research project, it is impossible to understand the implications of bone morphology without considering the relationship to surrounding soft tissue, and specifically the ACL.

1.3 BONE BIOLOGY AND THE CAPACITY FOR PLASTICITY

Bone Biology and Development

The development of the skeletal elements begins during the first three months of gestation (Allen and Burr, 2004). Most bones of the cranium, scapula, and clavicle are formed through a process called intramembranous ossification. This bone development method begins with the aggregation of mesenchymal cells that transition directly into osteoblasts. These cells then rapidly lay down woven bone, creating a primary center of ossification. While this is an important avenue for skeletal development, most of the human skeleton forms via endochondral ossification during which chondroblasts create a cartilage template that osteoblasts later ossify (Allen and

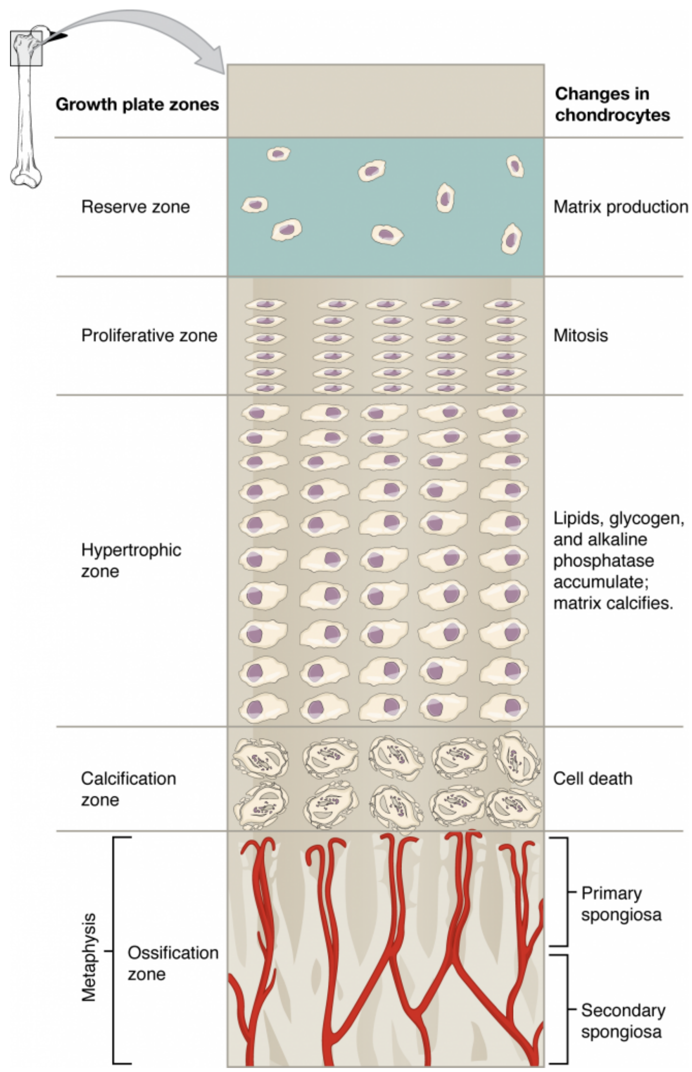


Figure 1.3. *Endochondral ossification zones. Photo sourced from Anatomy & Physiology, Biga et al. (2019).*

Burr, 2004). During endochondral ossification at the epiphyses, the forming bone is classified into 5 zones: (listed working from furthest to nearest primary ossification center) resting zone, proliferative zone, hypertrophic zone, calcified cartilage zone, and the zone of ossification (Fig. 1.3).

The four main types of bone cells are osteoclasts, osteoblasts, bone lining cells, and osteocytes. Bone lining cells are largely inactive, participating in neither formation nor resorption. When osteoblasts set to work, there is always a layer of unmineralized bone (or osteoid) underneath. Osteocytes can synthesize bone and, to a limited degree, can also resorb bone to perform day-to-day bone maintenance. The formative processes of osteoblasts and the resorptive nature of osteoclasts together create the basic multicellular unit (BMU) of bone remodeling (Bellido et al., 2004). Osteoblasts may also "become entombed" during the bone formation process, after which they become osteocytes, the most abundant bone cells (Bellido et al., 2004: 38). Osteocytes are enveloped by lacunae and each has a system of canaliculi that allows it to establish contact with other osteocytes and also have a transport system for osteocyte-generated proteins (Bellido et al., 2004). The distribution of osteocytes throughout the bone matrix, bone marrow, and bone surface allows them to efficiently detect tissue strain and trigger adaptive responses (Bellido et al., 2004). Like any cell, osteocytes have a natural life span, but this can be influenced by mechanical strain – apoptosis is more likely to occur in unloaded or heavily loaded bones. As in osteoclasts, cell apoptosis serves as a chemical signal to recruit bone cells for remodeling. Additionally, increased levels of estrogen and androgen can trigger heightened incidence of apoptosis (Bellido et al., 2004).

After initial formation, bone can be modeled or remodeled. Modeling always occurs on an existing bone surface and can either be formative – addition of bone mass by osteoblasts – or resorptive – removal of bone by osteoclasts. This process primarily occurs during active growth and development and achieves two major goals: (1) reshaping of the bone, and (2) changing "the position of the cortex relative to its central axis" (Allen and Burr, 2004: 80). Resorptive and formative modeling can also work in parallel to maintain bone shape during longitudinal and radial bone growth. The former removes periosteal bone while the latter spurs new bone growth on the endocortical surfaces. Bone drift, or the reorientation of the cortex in relation to its central axis, occurs when trabecular strut-like architecture shifts to better support local mechanical strain (Allen and Burr, 2004). In bone remodeling, bone formation and resorption do not occur in parallel, but in sequence. Osteoclasts first resorb the bone and then osteoblasts lay down new bone. Remodeling can be either targeted or stochastic (Allen and Burr, 2004). In targeted remodeling, signals such as osteocyte apoptosis or accumulating microdamage indicate to the body that certain skeletal locations require attention to prevent mechanical failure. However, in stochastic remodeling, osteoclasts resorb bone seemingly randomly and without a trigger signal, likely to perform preemptive maintenance and keep calcium levels stable. As humans age, the formative process of remodeling is outpaced by the resorptive processes, resulting in an overall reduction of bone mass and increased risk of fractures (Marks and Odgren, 2002).

Biomechanical Forces and Bone Response

Skeletal composition demonstrates a built-in mechanism for balancing rigidity and shock absorption during experiences of mechanical forces. Cortical bone is dense and is responsible for managing most of the load-bearing forces (Burr and Akkus, 2004). However, cancellous (porous) bone also absorbs some forces of movement and redirects excess force back to the cortical bone. The direction of primary biomechanical stressors can be ascertained by examining the orientation of collagen fibers. For example, bone that is primarily under tension will have longitudinally directed collagen fibers, while bone experiencing high compressive forces will have transversely orientated fibers (Burr and Akkus, 2004).

Collagen and hydroxyapatite together form a lamellar, or sheet-like, structure, except in the case of the rapidly laid woven bone. Cortical bone is the primary component of long bone diaphyses, while cancellous bone is mostly found in long bone metaphyses, vertebrae, ribs, and the iliac crest. The purpose of cancellous bone is to offer osteological elements an additional method for mechanical support that does not increase bone mass. This is achieved by the use of trabecular struts. Another important osteological relationship is the balance between mineralized and organic bone. If bone experiences too much of an increase in mineralization, it can become brittle, while a lack of mineralization would inhibit any sort of mechanical load bearing.

There are five main types of forces (Fig. 1.4) exerted on bone (Cullinane and Einhorn, 2002). A tensile force is created when linear forces are directed away from each other. Conversely, if these forces are oriented towards each other, the force becomes compressive. When forces are parallel but opposite directions, a shear force is generated. Bending forces occur when loads are concentrated at the epiphyses (imagine bending a stick by its ends), putting strain on the midshaft. Finally, torsion refers to a rotational or twisting stress that also creates shear stress throughout the bone. Stress can be quantified by a measurement of strain. Strain, in an example of compressive or tensile forces, represents the change in bone length prior to and following the mechanical stress. When mapping the way that bone responds to this mechanical stressor, a stress-strain curve is produced. The first part of the curve is linear and represents an elastic region of response, meaning that the bone will temporarily deform with the application of force but will return to its original shape once the force is removed. Following this linear region is a segment of plasticity, where the bone will have a long-term alteration. The stress applied at the transition to the plastic region is referred to as the elastic limit (Cullinane and Einhorn, 2002). At some point, the bone will fail under the maximum mechanical load and the

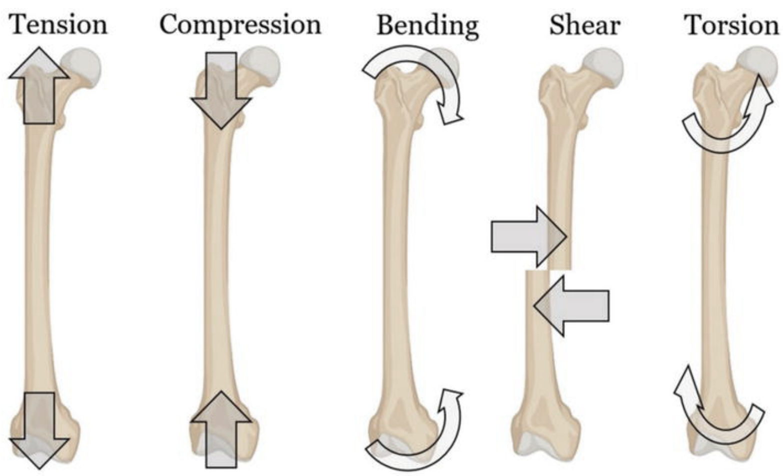


Figure 1.4. *The main types of forces/strains experienced by long bones. Image sourced from Alexandre et al. (2023).*

stress at this point is called the ultimate tensile/torsional/compressive strength. The strain at this point is called ductility (Cullinane and Einhorn, 2002).

As bone becomes accustomed to a new levels of mechanical force, the amount of stress needed to maintain a certain amount of strain decreases, and this is called stress relaxation (Cullinane and Einhorn, 2002). Bone is also anisotropic, meaning that a vertically oriented bone will respond differently to a mechanical force than that same bone oriented transversely or horizontally (Cullinane and Einhorn, 2002). When bone fails due to an inability to support a mechanical load, the bone may fracture. Some common fractures due to excessive loading are avulsion fractures and stress fractures. The former occurs when there is abnormally excessive force being exerted on tendons/ligaments generating a tensile force on the musculoskeletal attachment point, resulting in a small piece of bone breaking off. Stress fractures occur when the bone experiences fatigue failure from repetitive loading with no time for reparative processes, which leads to accumulation of microdamage.

Biological anthropologists typically discuss bone functional adaptation within the context of Wolff's Law. Wolff attempted to discern mathematical rules ("laws") that described bone response to mechanical forces, with specific focus on the axes of trabecular orientation in the femur (Ruff et al., 2006; Wolff, 1986). However, since Bertram and Swartz in 1991, numerous studies have cast into doubt the accuracy of these so-called laws. For instance, Robling and colleagues (2004) argue that Wolff fails to account for factors such as the amount of time over which the load is given. To illustrate, mice loaded four times throughout the day, rather than four times all at once, had 40-50%

greater increases in density and rigidity of bone. Wolff's law would not have predicted this, given that it only accounts for the load and number of cycles being the same (i.e., it would have predicted identical bone adaptations in each set of mice). Consequently, the concept of Wolff's Law is now invoked as a nod to the understood importance of mechanical loading in bone development and morphological responses (Ruff et al., 2006).

According to studies of bone functional adaptation, there are several aspects of mechanical strain that may be osteogenic (Robling et al., 2004). Strain magnitude and strain duration are relatively self-explanatory. Strain rate is the amount of time elapsed between the state of complete unload to maximum load. Strain frequency is defined as the number of loading cycles experienced per second. While the prior five factors largely determine whether a biological response is necessary or not, the polarity (e.g. compression, shear, etc.) of the stress determines the location of the response.

Studies of these factors within animal models have revealed five overarching rules for bone adaption (Robling et al., 2004). First, bone has a threshold for "normal" and it will only respond to mechanical strains (or strain rates) that exceed, or are below, such a threshold. Second, bone does not respond to static loading; the loads must be dynamic. To elaborate, a high magnitude of loading stress is not enough to stimulate bone growth, but relaxation from the load must also be experienced, creating an intermittent loading cycle (Hall, 2015). Third, given sufficient strain magnitude, a loading period can be short and still induce osteological adaptation. Fourth, higher rates of strain seem to be more osteogenic than lower rates. Finally, strain rate is determined through a combination of the strain magnitude and loading frequency.

According to Marks and Odgren (2002), skeletal cells are regulated by local microenvironments and local signals to strain. Therefore, strain throughout the body has less impact on osteological response than concentrated strain in a specific area. Several studies demonstrate the validity of considering localized strain on bone adaptability and morphological outcomes. For instance, consider research on variability in the femoral bicondylar angle, which is generally defined as the "obliquity of the femoral shaft relative to the midline body axis" (Waxenbaum and Stock, 2016: 334). As discussed earlier in this chapter, the bicondylar angle needs input strain as an impetus to develop. Babies are not born with bicondylar angles and nonmobile persons develop it minimally or not at all (Tardieu, 2010). Females generally display a greater degree of obliquity due to the difference in shape between male and female pelvises, resulting in distinct pattens of ambulatory strain. (Waxenbaum and Stock, 2016). Additionally, older adults display lower bicondylar angles than younger adults, perhaps reflecting decreased mobility in the older group (Waxenbaum and Stock, 2016). Therefore, the femoral bicondylar angle is just one example that strengthens claims of strong "plastic" responses in the femur.

The presence of a "dominant" limb also results in asymmetrical development of the long bones. Behavioral studies report significant favoring of the right foot, (e.g., when kicking a ball, this is the preferred foot) (e.g., Auerbach and Ruff, 2006). While one might assume that the dominant leg would experience more strain and develop thicker cortical bone as a result, studies find that the non-favored leg exhibits more robusticity (as seen via cross-sectional analysis). Auerbach and Ruff (2006) try to reconcile this information with mechanical strain theory by suggesting that higher mechanical loads are experienced by the lower left limb when the right leg is used to manipulate objects. Cowgill (2012) adds further complexity to morphological analysis of the femur by demonstrating that mobility type/manner is balanced with populational adaptations to cold environments (and as an extension of logic, likely hot environments). To expand, cold-adapted bodies are typically stocky, with foreshortened limbs but high body mass (Cowgill, 2012). Mechanical strain can only alter the stocky or lanky body type that already exists, so the final morphological outcome represents the interdependence of at least two variables. Based on previous research, the femur: (1) displays remarkable existing variation and capacity to respond to a range of mechanical stress inputs, and (2) develops based on a combination of variables such as genetics and localized strain. The groundwork laid by these types of studies informed the three hypotheses outlined later in this chapter, as well as strong consideration that the results of this dissertation will show interaction between the variables studied.

1.4 MEDICAL LITERATURE

Why is the Intercondylar Fossa of Particular Interest?

Researchers first became interested in the link between distal femur shape, specifically the intercondylar fossa, and human movement due to the apparent relationship to anterior cruciate ligament (ACL) injury. Clinical research is concerned with the high modern rates of ACL rupture because these injuries are costly in terms of time and money, and long-term complications are extremely likely. Some individuals may never regain full mobility of the affected knee. ACL physiology may partially explain high numbers of injury, as its angled orientation between the distal femur and proximal tibia attachment points means that it frequently experiences shear (twisting) forces (Lovejoy, 2007). Rates of ACL injury have been repeatedly linked to size restrictions of the intercondylar fossa (Anderson et al., 1987; Good et al., 1991; Lund-Hanssen et al.,1994; Shelbourne et al., 1998; Souryal et al., 1988; Souryal and Freeman, 1993). As previously mentioned, the more stenotic (constricted) the notch size, the more likely the ligament is to experience trauma from contact with the lateral bone wall.

Medical research has been primarily concerned with addressing this issue by looking for risk factors for stenotic notches. This means that a majority of studies are attempting to link aspects of "biological" identity such as sex or population (sometimes referred to as "race") with increased risk for stenotic notch development. I argue that this type of research avenue is limiting. These studies are predicated on an assumption that genetic factors are the primary determinants of notch morphology without any prior investigation attempting to rule out other possible contributing variables. In the hypotheses to be laid out later in this section, I intend to show that more anthropologically guided questions, such as *why* certain races or sexes may be disproportionately developing stenotic notches and potentially experiencing ACL injuries, is a more powerful way to examine a biomedical question. Rather than stopping at detecting trends in intercondylar fossa size, I seek explanations for why these trends exist, and ask if it might be possible to intervene in some way to decrease the likelihood of developing a stenotic notch. Before delving into the anthropological theory framing this research, I first present a brief literature review of the most pertinent medical findings regarding the dimensions and shape of the intercondylar fossa.

Previous Biomedical Research Regarding the Intercondylar Fossa

Clinical research studies have utilized a variety of methods to characterize and describe the intercondylar notch. A small cadre of studies characterize the fossa by its "roof" and shape of its rim (borders). Farrow and colleagues (2007) studied 200 femora from the Hamann-Todd collection to characterize notch morphology, focusing on the lateral wall and posterolateral rim, rather than the entirety of the notch. The results of this research indicate that a distinct, straight border was present in almost ninety percent of the sample population, while indistinct and "distinct, V-shaped border[s]" were seen to a much-diminished extent (Farrow et al., 2007: 2150). From these data, the authors conclude that the morphology of the intercondylar notch is relatively stable. The veracity of this broad characterization is not clear as the authors only analyzed certain parts of the fossa.

The intercondylar shelf, or notch roof, has also previously been studied for potential use in the field of forensic anthropology by aiding in the assessment of race from skeletal remains (Craig, 1995). Craig (1995) concludes that this feature does show variation by race because individuals with extreme shelf angles can be correctly classified by race a majority of the time. While this feature may be helpful in ancestral estimation for poorly preserved remains, it does not seem clear that race is the true explanatory factor for this variation. As any anthropologist will explain, race is not a biological reality, but rather a cultural construction. However, even if "race" were replaced with the more accurate term of “ancestry,” it is still left unaddressed why genetics are assumed to be the primary variable of influence, especially when the potential for plasticity at this joint is repeatedly demonstrated throughout the literature. I find myself asking if white and black Americans might occupy different work positions and if this might result in intercondylar notch shelf angle differences between these groups. Are the results of this research less about race than they are about differences in societal opportunities? Additionally, this type of biomedical research, in which a very small feature is used to infer race of an individual, runs the risk of reifying race as a biological reality in the minds of many. In pushing back against this kind of biological determinist study, I utilize race as a category representative of larger social frameworks, rather than a variable with inherent biological meaning on its own terms.

Despite the existence of an array of methods to quantify variation at the intercondylar notch, the most popular by far is the use of notch width index (e.g., Alentorn-Geli et al., 2009; Anderson et al., 1987; Chandrashekar et al., 2005; Hoteya et al., 2011; Muneta et al., 1997; Murshed et al., 2005; Shultz et al., 2012; Zeng et al., 2013). The notch width index (NWI) is defined as the ratio between the femoral notch width and bicondylar width, as measured along the plane of the popliteal groove (Fig. 1.5). Researchers that utilize NWI believe that it corrects for the natural sexual dimorphism in body size between the sexes and makes it more reliable to compare notch morphologies between sexes and populations. Most clinical literature utilizing NWI relies on measurements calculated from radiographs, a consequence of being unable to access the physical bone in patients. Unfortunately, the accuracy of comparing radiographic measurements is dependent on the ability to position the patients in the same way for every image capture. Small changes in posture or stance can alter the angle of the bone in the image, resulting in difficulty repeating and comparing landmark measurements.

Moreover, NWI studies grapple with another limitation – small sample sizes. Once again due to the nature of studies involving live patients, sample sizes in most clinical studies are highly restricted. Even when clinical researchers can study deceased individuals, sample sizes still tend to be small, such as in Muneta and colleagues' (1997) study of sixteen cadaveric knees. The lack of large population sizes imposes limits on the statistical power of results, and I argue that this contributes to the various, and sometimes contradictory, hypotheses about the factors which influence notch morphology. This dissertation provides an opportunity to draw conclusions from a larger data set and run comparisons to other smaller previous studies.

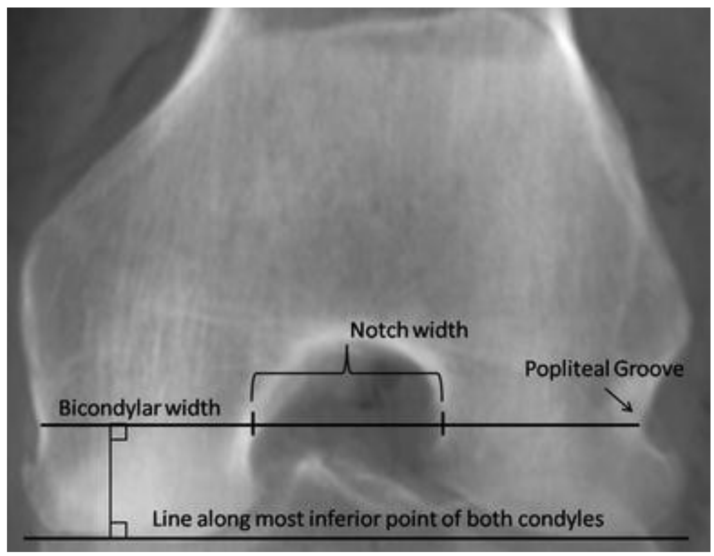


Figure 1.5. *Elements of the notch width index illustrated on a radiograph. Image sourced from van Eck et al. (2010).*

Taken together, a majority of NWI studies conclude that there is a clear link between stenotic (abnormally low NWI) notches and ACL injury risk (e.g., Souryal et al., 1988, 1993; Zeng et al., 2013), likely because ACL size varies little between people (Muneta et al., 1997). Consequently, "mismatch between the size of the ACL and the volume of the notch may predispose the ACL to injury," especially during activities requiring rotation and translation at the knee joint (Muneta et al., 1997: 72). However, I contend that clinical studies of NWI have several drawbacks. First, most studies that investigate the etiology of stenotic notches make underlying assumptions that the condition is either acquired as a result of ACL rupture, or that narrow notch dimensions are congenital (Anderson et al., 1987). I argue that this creates a gap in the literature: most researchers are not thinking about or considering the role of plasticity at this locus. The largely static image of the intercondylar notch advanced by medical fields not only overlooks the potentially large role of activity in shaping morphology, but also neglects to acknowledge the natural narrowing trend throughout the life course, as aging leads to shifts in gait mechanics (Murshed et al., 2005).

Perhaps the greatest blow to the confidence in NWI methods comes from Shelbourne and colleagues (1998), who indicate that the acceptance of NWI as an accurate tool for quantifying the notch was based in faulty preconceptions. More specifically, the use of NWI assumes that "notch width and femoral bicondylar width increase with increasing height, and therefore this ratio should be a valid means of standardizing patient size" (Shelbourne et al., 1998: 403). Unfortunately, this does not hold true. While femoral bicondylar width does indeed increase with height, notch width does not (Shelbourne et al., 1998; Shelbourne and Kerr, 2001). Therefore, absolute notch width, rather than NWI, is likely a better way to assess notch size. Though some subsequent studies would adjust their methods in consideration of this (e.g., Boden et al., 2010; Lonner et al., 2008) most researchers continue to rely on NWI without addressing the controversy or drawbacks. This dissertation does utilize NWI as a secondary method, but only to allow these results to be in conversation with other studies and as a comparison to trends in notch volume. It does not assume that NWI controls for body size or can reveal everything needed about fossa size.

While there are clearly limitations to the use of NWI, my main concern is the singular reliance on two-dimensional (2D) measurements, which oversimplifies an incredibly complex joint. Further, the use of radiographs to obtain these measurements is rife with issues, as the positioning of the joint can make distances in the generated images appear longer or more compressed, depending on the angle of orientation (Boden et al., 2010). In other words, 2D radiographs "provide only a projection of bone shape and do not provide a complete picture of the patient's anatomy" (Mahfouz et al., 2012: 173). Technological advances, though, have made it more of a possibility to approach notch characterization from a more accurate, three-dimensional perspective. The use of geometric morphometrics is one popular way of visualizing the knee in three dimensions (e.g., Mahfouz et al., 2012; Stevens and Strand Vidarsdottir, 2008), but there is still an obvious deficit in the use of 3D modeling to generate quantitative, rather than qualitative, data.

To summarize, medical literature has attempted to explain variation in intercondylar notch size by looking for inherent sex- or race-based differences in bone morphology (e.g., Chandrashekar et al., 2005; Gill, 2001; Murshed et al., 2005). However, by and large these studies have relied on two-dimensional imaging techniques due to cost efficiency and the inaccessibility of dry bone in living patients. While both medical researchers and I agree that uncovering risk factors for stenotic notch development is critical to improving lives, I propose a new approach to this problem by shifting the focus from living individuals to historical skeletal collections. In skeletal collections, dry bone is more easily studied, allowing me to capitalize on an approach yet unseen in the medical literature – 3D modeling of the intercondylar notch volume on dry bone. The reliance of clinical studies on two-dimensional measurements oversimplifies an incredibly complex joint. My novel 3D methodology is free from this limitation and provides a more accurate view of the space within the knee. This will be discussed further in the Materials and Methods chapter.

1.5 HYPOTHESES

As described in the previous section, the assumption that stenotic notch development is primarily linked to genetics has not been extensively studied due to methodological limitations. Biomedical studies mostly involve living patients, therefore physicians are extremely limited in terms of sample size and ability to obtain accurate measurements of the joint and surrounding bone. An anthropological approach utilizing a well-preserved and documented skeletal collection (in this case, comprised of individuals from Santa Clara County born between 1842 and 1910) provides an opportunity to test hypotheses largely unavailable to physicians.

Moreover, anthropological analytical methods present avenues for considering the roles of social, economic, and temporal contexts in shaping metabolic and mechanical stressors, as well as genetic clustering. By identifying patterns in notch morphology and explaining why certain groups are more likely to develop stenotic notches, the results of this research can aid in understanding ACL injury patterns in modern populations and help develop intervention programs for populations experiencing disproportionate risk/burden. In this research, I hypothesize that while the etiology of a stenotic intercondylar notch is complex and may involve interaction between multiple factors, the primary influence is metabolic stress, habitual mechanical stress, or genetic factors. These hypotheses are not mutually exclusive and one, two, or all three proposed factors may be acting together.

Hypothesis 1: The development of a stenotic (abnormally narrow) notch is linked to experiences of systemic, metabolic stress.

Metabolic stress is experienced when disease, exposure to toxins, or severe lack of nutrition (for example) place heavy energetic demands on the body, resulting in disruption of growth or plasticity to allocate that biological energy to survival and healing rather than maintenance and growth (Brinkely and Ives, 2008). Acute need for reallocation of energy to essential functions may limit osteological growth, stunting stature and inhibiting joint development/bone growth in response to mechanical stressors (e.g., Agarwal, 2016). Canine studies demonstrate the occurrence of growth disruption narrowing the intercondylar notch, and it is worth investigating whether the same mechanism functions in humans (e.g., Comerford et al., 2006). Some of the most common osteological signs that can be correlated with metabolic stress include cribra orbitalia, porotic hyperostosis, periosteal lesions, and linear enamel hypoplasia (LEH) (Beatrice and Soler, 2016; Blakey et al., 1994; Brinkley and Ives, 2008; Dent, 2017). Cribra orbitalia, porotic hyperostosis, and LEH appear during early life, and therefore may reflect an individual's region of origin rather than the conditions of Santa Clara County, but still provide information regarding socioeconomic status and experiences of structural vulnerability (Brinkely and Ives, 2008; Hutchinson and Larsen, 1988; Lanphear, 1990).

19th-century San Francisco and the surrounding area presented an environment filled with numerous challenges. The discovery of gold attracted a heavy influx of male prospectors who quickly overwhelmed available housing, leading to the erection of tent cities and shanty towns (Buzon et al., 2005). Lack of plumbing and running water – and general closeness of the quarters – invited rodent and insect infestation, burdening bodies with disease and parasitic infection, the biological stress of which was exacerbated by rampant malnutrition (Asbury 1933; Buzon et al., 2005; Lewis Publishing Company, 1892). Where plumbing was available, it drained into the edge of the San Francisco Bay and other nearby water sources, causing concerning levels of pollution (Buzon et al., 2005; Lewis Publishing Company, 1892). Due to large amounts of immigration and job competition, access to resources – as in many places throughout the United States – was distributed unequally (Angel et al., 1987; Dent 2017; Parrington and Roberts, 1984; Rathbun, 1987). Unique life trajectories across social groups result in different patterns of metabolic stress (Dent, 2017). Thus, if stenotic intercondylar notches result from a disruption in growth or plasticity, then I hypothesize that the group(s) with the narrowest intercondylar notches will present with the greatest osteological evidence of systemic stress. If metabolic stress during growth is a cause of stenotic notches, there should be a correlation between narrow notches and osteological signs of stress in childhood. Though stress is endemic in the population, differences between individuals who survived childhood should still be observable. If there is no correlation, one of the other hypotheses is likely correct/there is an alternative explanation for notch size.

Hypothesis 2: The etiology of a stenotic intercondylar notch is linked to experiences of habitual mechanical stress.

Mechanically stressed joints have two possible avenues for relief: changes in size or shape (Tamvada, 2014). By depositing additional bone and enlarging the joints, mechanical forces can be dispersed over a greater surface area, eliminating concentrated stresses that put the bone at risk for fracture (Allen and Burr, 2014). Shape changes are an alternative method to reach the same outcome. Because the remodeling process is initiated and maintained by intermittent joint loading (Hall, 2015), locomotion and occupational activity (e.g., Agarwal, 2012; Mulhern and Van Gerven, 1997; Perry, 2004) are important drivers of "plastic" response at the distal femur. Evidence of morphological changes in response to mechanical loading forces includes the high incidence of directional asymmetry toward the dominant limb and cross-sectional differences between groups traversing distinct types of terrain (Auerbach and Ruff, 2006; Holt et al., 2018; Holt and Whittey, 2019; Plochocki, 2004). There are, however, limits to plasticity due to functional necessity, and articular surface areas and bone length variations are much more conservative than diaphyseal shape and cross-sectional dimensions (Lieberman et al., 2001). Excessive pulling of the ACL results in a thickening of the attachment point on the intercondylar wall, and compressive stresses of walking can expand or reshape the distal femoral epiphysis (Norman et al., 2017; Smith, 1962). Thickened bone and the development of osteoarthritis can further narrow the intercondylar notch space without disrupting tibiofemoral articulation (Auerbach and Ruff, 2006; Lieberman et al., 2001).

To characterize the impact of mechanical stress on the lower limbs, I will determine robusticity measures of the femur. I focus on femoral measurements not only because postcranial dimensions more accurately reflect mechanical loading, but because the femur houses the intercondylar notch and is thus an appropriate indicator of stress at that locus (Vercellotti, 2018). Based on the principals of beam theory and bone functional adaptation theory, increased mechanical loading should be detectable in the size parameters of the distal femur, including the notch, as well as the diaphyseal measurements of the long bone (Agostini and Ross, 2011; Lieberman et al., 2004; Macintosh et al., 2013). I propose to use both overall robusticity and osteoarthritic changes as evidence of mechanical loading. If the development of a stenotic intercondylar notch is related to levels of mechanical stress (terrain is not a significant confounding factor here as the geographic focus is localized and individuals had resided, on average, about 36.5 years in California), I hypothesize that those exhibiting the greatest robusticity indices will have the narrowest notches, as the articular area of the distal epiphysis likely expanded to help dissipate forces over a greater area, and the development of osteoarthritic lipping may have infringed on the notch space.

Hypothesis 3: Notch size is linked to genetic factors.

The third and final hypothesis to be tested is that medical researchers are correct in their assumptions that the size of the intercondylar notch is primarily linked to genetic factors. Each individual in the University of Iowa-Stanford Collection (UISC) was issued a death certificate upon which a racial category was indicated. The issue with taking this category at face value is that it does not question the accuracy of this postmortem categorization and it negates any recognition of population admixture and genetic diversity within socially-determined racial categories. To address this shortcoming, I will create new genetic groups (sub-populations) through the documentation of nonmetric traits and use of cluster analysis. This will reveal whether similar intercondylar notch dimensions are correlated with genetic relatedness.

As early as the 1960s, anthropologists were investigating nonmetric traits for use in establishing lineages and relatedness (Berry and Berry, 1967; Killgrove, 2009). Cranial and postcranial nonmetrics will be documented - the former because they are the best studied and most reliable (only minimally influenced by climate, diet, or other environmental factors), and the latter due to cranial preservation limitations in the collection (Buikstra et al., 1990; Harvati and Weaver, 2006; Killgrove, 2009; Pietrusewsky, 2020; Relethford, 1994, 2001; Roseman, 2004; Roseman and Weaver, 2004; Smith et al., 2016). The primary assumption underlying the use of nonmetric traits for biodistance analyses is that any change in allele frequencies is reflected in phenotypic expression frequencies (Killgrove, 2009). If this assumption holds, and if intercondylar notch size parameters are indeed influenced by genetic factors, I expect to see more genetically similar individuals clustering together on the notch width/volume spectrum. Put differently, I would not expect to see closely related individuals demonstrating both very wide and very narrow notches or to exhibit a large spread in values; instead, I hypothesize that related groups will cluster together in notch values.

1.6 CONCLUSION

Bone possesses the incredible capability to functionally adapt to stressors throughout the life course. Although the aging process results in a diminished capacity for such, it does not entirely inhibit remodeling but rather limits the degree to which it can occur. The biomedical studies discussed in this chapter demonstrate the remarkable range of developmental responses exhibited by bone, and the femur in particular, in response to localized strain. By acknowledging that mechanical forces and population history (i.e., genetics) seem to both have some influence on the development of femoral characteristics, such as degree of bicondylar angle, it would make sense that these may also have some bearing on intercondylar fossa shape. Drawing on the biomedical background, I am concentrating on testing three specific hypotheses, as well as acknowledging that the answer to the question of stenotic notch etiology is likely some combination of all three hypotheses. In the next chapter, I will orient this research theoretically and historically. I offer my perspective on what it means to research anatomical teaching specimens, given the questionable history of obtaining remains, and grapple with this issue on both a theoretical and ethical level. The next chapter therefore provides crucial social context for analyzing the osteological data.

Chapter 2: The State, Biopower, and Sociohistorical Context of the Santa Clara Valley

2.1 INTRODUCTION

The skeletal collection of focus for this research is the University of Iowa-Stanford Collection (UISC). Originally named the Stanford-Meyer collection and used as a teaching tool for Stanford's medical students, the UISC is now located in Iowa City at the Office of the State Archaeologist. More information about the UISC is discussed in Chapter 3 but broadly, this collection is well-documented and sparsely studied. It is comprised of individuals born between the years 1842 and 1910 and who died between 1929 and 1952 in the Santa Clara Valley of Northern California.

Of the individuals with a known birth location, approximately half were born in the United States, while the rest were foreign born. To accurately interpret and understand the results of statistical testing that will follow, it is important to contextualize these individuals as more than just a catalog number. To those living in California during this time period, ethnicity and nationality had a specific meaning. Individuals arriving to California from China were treated drastically different from those arriving from Germany and Great Britain (Logan, 2015; Shah, 2011; Wilson Moore, 2003). The category of whiteness was more flexible in California than in other states, allowing for the Irish to claim this label, and the social mobility of black individuals was also enhanced in comparison with the rest of the country (Barkan, 2007; Broussard, 1993; Jacobson, 1984; Prince-Buitenhuys, 2016; White, 1991; Wilson Moore, 2003). This is not to say that racism, bigotry and discrimination did not exist in California, but only that it existed in a different form and served a different purpose. This fear of Others (even the endogenous, as “Okies” entered the state en masse in the 1940s) was expressed fluidly throughout this period, morphing and changing to fit the needs of those in power.

I lead with theory to provide a framework through which to understand how a particular historical context relates to the body. In California, whose bodies were expendable and whose were not? Whose bodies were legible to the State only for the purposes of exploitation? How did norms surrounding gender roles shape what kind of labor men and women participated in as well as the racial composition of those positions? Which European groups were allowed to achieve the label of “white” and therefore be assimilated into the sphere of power, granting them what Du Bois calls a “psychological wage”? These questions *must* be answered in the context of historical Bay Area California and Santa Clara County, for the responses would differ were we examining Chicago, New York, or even Los Angeles. Our social context becomes embodied in our corpus as it shapes our life chances, accessible resources, potential occupations, and even regard for other groups. Therefore, theory offers us an avenue for connecting the social, the economic, and the political with the remains that we examine.

2.2 THEORY

Most medical research investigating the etiology of a stenotic intercondylar notch focuses on identification of risk factors. Risk factors are, in this case, biological- or behavior-related aspects that show a strong association with intercondylar notch size. For instance, previous ACL injury (e.g., Babalola et al., 2021; Jha et al., 2022), ACL size (e.g., Wang et al., 2019), sex (e.g., Patel et al., 2021), and race (e.g., Gill, 2001) are all common risk factors investigated in literature associated with the femoral intercondylar notch. In all of these articles, and the many more that I have and will cite throughout this dissertation, it is exceedingly rare to find publications on this subject providing insight into “upstream” (structural/root) causes for these patterns or a theoretical lens that contextualizes why they exist.

Bioarchaeologists, on the other hand, are interested in the intersection of labor and osteological development in past populations, using theoretical frameworks to understand how the biological intersects with the social. In bioarchaeology today, it is almost standard practice to reference how engrained social norms regarding accepted behaviors of certain classes, races, or age groups not only inform the way people act – what Bourdieu (1977) refers to as *habitus* – but also places limits on their capacity for agency. Bourdieu himself avoids closely defining *habitus* but is clear that it lives at the nexus of practice and structure. *Habitus* is an internalized expectation for how the world works to the individual, and positions humans within the larger social structure. Because *habitus* is acquired through enculturation processes, it does place limits on an individual’s capacity to act, improvise and innovate (i.e., agency), but does not eliminate it (Bourdieu, 1977). By being part of a community or society, individuals are involved in repetitive actions that inform, via socialization, appropriate ways to think, perceive, and be in the world (DiAngelo, 2018).

If one’s *habitus* aligns with the dominant group’s norms, then the individual is endowed with “embodied cultural capital” (Miles et al., 2019: 310). For instance, affluent or otherwise insider individuals can better navigate institutions like higher education more efficiently and have the "know how" to exploit loopholes in the legal system. It is in this way that *habitus* reflects how "class is actually written into people's way of being" as privileged sociocultural knowledge is transmitted generationally (Ridgeway, 2014: 9). Bioarchaeologists of the 21st-century have begun employing this concept as a recognition that the body is not a secular object (Sofaer, 2006). Beyond influence of the physical environment, the body is a tangible reflection of habitus during the lifetime, which reflects resource access and life chances (Becker and Juengst, 2017).

However, there seems to be a fault in our logic. Despite an understanding of how bodies come to be socially constructed, bioarchaeologists are largely operating from a perspective that presents physiological differences as truth. Bioarchaeologists equipped with standardized forms go through the routine motions of checking off boxes that indicate age, ancestry, and sex. We reduce a continuous variable (yes, even sex exists on a spectrum) to binary or limited categories, and little consider the meaning of checking the box for "indeterminate." Human biology is complex, and the reduction of its variability represented by the methods of categorization on these forms must be recognized as an abstraction of reality. Forensic anthropologists go one step further and attempt to discern a probable racial group from remains. The intention is to aid in the process of identification, but an accidental byproduct is that race is again presented as aggregation of innate biological differences. The underlying implication of these methods is that race and sex are based on biological "truths" with the sociocultural component largely relegated to the background. In contradiction to this, the theoretical perspective employed in this research reorients the component of social construction back to the foreground. I argue that race is not a secular category, but one that becomes “real” when resource and opportunity access is asymmetrically granted based on how well individuals seem to meet dominant norms. In other words, humans recognize morphological and behavioral distinctions between each other and develop social structures that both reify and magnify these differences; privilege and poverty materially manifest by and through social norms and patterns of opportunity.

I situate my work at the nexus of three theoretical frameworks. Perhaps most important is Foucault’s concepts of biopolitics and biopower, which address how the State works to legislate who counts, or which bodies are exploitable and which “matter” (Foucault, 2008). This does not have to take place only via explicit legislation but can also include loopholes or other avenues of structural violence that become state-endorsed through the lack of condemnation or intervention by or through the government. The idea of biopolitics overlaps neatly with James Scott’s notion of (il)legibility, as he outlines in his book *Seeing Like a State* (1999). When Scott uses this term, he is referencing government-managed forests and other natural resources, but the concept can neatly carry over to discuss how the U.S. government has placed black individuals and all colored bodies in a limbo. It must render them partially legible to recognize and exploit them as a source of expendable labor, but it cannot make them fully legible or they would be able to reap the benefits of citizenship bestowed upon white masculinity.

Finally, Bourdieu’s habitus can bridge the gap between biopolitics and (il)legibility by explaining the physical embodiment of these sociopolitical institutions (1977). By being part of a community or society, there are inherent normative standards that define what the world should look like to an individual, based both on how that individual defines his or herself and how they are perceived by others. Bioarchaeologists assert that these expectations are internalized and expressed via habits or dispositions. The overarching understanding is that there is a dominant group which creates social norms reifying their dominance while marking minority groups as the "Other." This translates into differential treatment, including labor hierarchies. The confluence of biopolitics, (il)legibility, and habitus creates what Damien Sojoyner (2016: xii) calls "enclosures," or the "unseen forces that are just as powerful as the physical manifestations" that create unequal life opportunities and become corporeally encoded as skeletal changes.

Foucault and Biopolitics

Perhaps most important to this work are Foucault's concept of biopolitics, which addresses how the State works to legislate who counts, or which bodies are exploitable and which have value (Foucault, 2008). For Foucault, the rise of biopolitics begins in the 1600s when informal forms of acquisition, such as raiding, are gradually replaced with legalized (i.e., state-sanctioned) means of developing resource- and intergroup-relations that were often asymmetrical, consistently favoring some groups over others. As such, integral to the exercise of biopolitical means are "processes of differentiation and valuing" that apply some normative standard of being – in this case the heterosexual, white male – as the yardstick against which all other groups are measured (Escobar, 2016: 100). The more distant a group from these norms, the more difficult it is for the State to assimilate them into proper, productive, neoliberal citizens that are not dependent on State resources and contribute to the national economy. When people are labeled as deviating from neoliberal norms, they become the non-citizen, or in the case of persons of African descent in American history, the anti-citizen (Glenn, 2002). Consequently, the State feels little obligation to provide resources and opportunities to those who choose to be nonconformist to established social and labor hierarchies.

Underlying the exercise of biopolitics is access to biopower. Another Foucauldian term, biopower references the ways in which the body is disciplined and regulated so as to control a populace (Foucault, 1978). Some examples of biopower include the use of birth and death certificates as a method of validating whose existences are valued by the State. Biopower can also manifest in necropolitics, an amplification of biopolitics that specifically deals with instances when the death is forcibly put-upon certain groups (Mbembe, 2003). Biopolitical (and necropolitical) disenfranchisement and violence do not have to occur via explicit legislation, but also manifest through legal loopholes or other avenues of structural violence that become state-endorsed through the lack of condemnation or intervention by or through the government. In fact, it is often the most subtle modes of discrimination that are the most enduring, as they are easily normalized and therefore not critically considered.

Typically, the State normalizes biopolitical control through narratives. For instance, consider the mythos of the American dream. Many of us, myself included, have been told that if we work hard enough, we can buy that house with the white picket fence with the picture-perfect nuclear family inside. The narrative of economic advancement providing social mobility through hard work and dedication is pushed onto immigrants in the U.S. In most Western countries, Capitalism is the economic mechanism through which the State operates and maintains power status quo. The State uses accrual of Capital – monetary and cultural – as the basis for social class formation (Gramsci, 1971). According to Gramsci (1971), the Capitalistic State operates primarily through the realms of political and civil society, the former ruling through force and the latter through consent. The marginalization of lower social classes manufactures the appearance of "consent" and allows for the reproduction of the dominant group's ideology through media and social institutions (Gramsci, 1971; Heywood 1994). The omnipresence of the ruling group's beliefs, perceptions, and values as accepted social norms is what Gramsci termed "hegemony" (1971). In a Capitalist State, hegemony is utilized to correlate work ethic and economic production (in the lower classes) with moral values for the benefit of the elite social strata (Kurtz, 2001: 15; Kurtz and Nunley, 1993).

Narratives glamorizing hard work are necessary to keep marginalized groups content within coercive labor regimes with promises of future returns. Consequently, poverty and lack of status become the result of an individual's moral deficiency, a lack of desire to work hard enough for success and making them undeserving of aid/relief programs (Katz, 2013). Public dependency on State resources is considered by the ruling group to be morally repulsive and the direct result of laziness and irresponsibility (Cacho, 2012). The painting of social class as reflective of an individual's value destabilizes the worldview of poor whites. By all outward appearances, they should belong to the upper echelon but are continually unable to access this membership (Glenn, 2002). To make sense of this phenomenon, many working-class whites direct blame towards immigrants and persons of color, rather than the larger structures in place such as the State and Capital (Glenn, 2002; Rubin, 1994). Immigrants and persons of color must be differentiated even from poor whites, otherwise the door to full personhood and all the rights of the privileged group is ajar.

The concept of biopolitics is crucial to this research because it explains how politics and human biology intersect. More than this, it explains how the State seeks to order human bodies and lives in accordance with its desires of maintenance. Those in positions of governance and power are primarily members of the privileged group. Therefore, those creating laws and social norms can and do structure these control mechanisms to keep certain groups in positions of exploitation so that the groups in power can maintain their status. As Escobar (2016: 6) concisely describes it, "the law is an active agent in producing unequal relations that center on constructing exploitable bodies" (Chang, 2000; Chavez, 2007; De Genova 2002, 2013a, 2013b; Rodriguez and Paredes, 2013). Throughout American history, this has meant that persons of color, particularly black individuals, have been the furthest distanced from resources and opportunities available to fully-fledged citizens (e.g., Anderson, 2016; DiAngelo, 2018; Epp et al., 2014). With few other options, those in minority groups had little choice but to enter into coerced labor regimes of low wages and back-breaking work. Examining American history with a biopolitical lens in mind allows me to make connections between the biological (osteological) and the larger social contexts that influenced labor patterns. Moreover, examining the biopolitical climate allows me to consider temporally specific conditions of labor and marginalization, while also identifying those that have persisted through time and remained present in the modern era. In other words, examining the biopolitical presents an opportunity to make research of historical labor and social hierarchies relevant to modern society by exposing the continuance of state-directed racialized, structural violence.

(Il)legibility and the State

Like Foucault's concept of biopolitics, James C. Scott's notion of (il)legibility (1999) concerns the driving forces behind State policy decisions. For Scott, State control is exercised most effectively through immanent power. Immanent power is a form of control that is already embedded in a particular tactic of the state, and thus endemic to a particular regime (1999:19). It is not made explicit or pronounced but underlies State programs and becomes normalized through assumptions of its validity. For the purposes of this research, the most relevant form of immanent power as exercised by the American State is in its construction of a racial democracy. In this type of political scheme, knowledge is produced around a phenotype – when a physiology is inhabited, an individual immediately assumes a place in the knowledge regime. To be a certain gender or skin color is necessarily to "know" the role to be played in society. To deviate from this undermines State efforts to maintain stability in the national social strata.

Scott (1999) further asserts that policy decisions by the State are a form of counterinsurgency. Counterinsurgency is a method for using military strategy to pacify, or render legible by military force, the complexity of local forms of being (Scott, 1999). Put another way, heterogeneity – diversity – is a threat to the State. Conformity is the only way that State regimes remain unchallenged and monolithic. The State must resolve differences in opinion and alternative ways of being lest they garner public support and present a challenge to the exploitative social hierarchies that it guards as sacred. Therefore, the foremost purpose of statecraft is to take complexities and render them legible. One way in which this is accomplished is by standardizing aspects of biopower, such as via Social Security numbers and birth certificates. Normalizing these legalities accomplishes two main goals: (1) it relegates them to the realm of the mundane, minimizing critical challenges to these forms of power over the human body, and (2) it advances the implicit notion that persons must fit into preassigned boxes in order to be documented, and therefore be seen as having value from the State's perspective.

To be rendered fully legible, then, is a compromise. It is to give up the freedom of choice in order to have access to the benefits and resources provided by the State. However, not everyone can access the category of "legible." Persons of color particularly are kept in a state between legibility and illegibility. They must be legible to a degree in order to be enumerated, controlled, and exploited for their labor. Yet they must also be prevented from complete legibility, for this would entitle them to citizenship and full access to the status of the human. Partial legibility explains why persons of color can participate in the capitalist system, but not to the degree that would allow the social mobility afforded to white people.

The American scale of (il)legibility was entrenched during the colonial period because integral to the success of the economy was the cheap mass of slave labor. Financial gain for the white planter class was predicated on the ownership of a labor source, and because this labor was considered property, it was important that it could be counted and documented (Du Bois, 1998). However, this was the extent of State legibility that could be afforded to enslaved persons. To consider them more than property was to acquiesce that they were human, and would imply that their votes and opinions should matter to the electorate. By extension, this would give enslaved persons legislative power, which due to their sheer population size, could quickly topple the precarious, white-dominated social hierarchy. It was within this context that the notion of black individuals as the anti-citizen arose, and their existence became synonymous with antagonism towards white privilege.

This research is concerned with how biopolitics were utilized in the 19th and 20th centuries in the United States to continue patterns of racialized colonial violence that marked some persons as legible and remaindered others to a transitional state of partial (il)legibility. I argue that this has less to do with conceptualizations of character than it does a capitalist economy founded on the ownership of labor, with those in power desiring to retain that power and those exploited wanting to find avenues for disruption. One of the primary driving forces behind this research is the understanding that minorities were rendered partially (il)legible for the purposes of harnessing their labor while continuing to distance them from social resources awarded to fully legible citizens. Further, this research argues that though there were undoubtedly poor, laboring class whites during this time period, they were granted what Du Bois (1998: 767) calls a "psychological wage" in that they experienced wide acceptance in social and political spheres. Therefore, laboring whites were legible in a way that black persons and other minority groups could not be. The conceptualization that white individuals were somehow more deserving than persons of color also protected them from the hardest, most precarious laboring positions – such as those in the extractive industries – which were reserved for the country's most illegible populations.

2.3 HISTORICAL CONTEXT

Birth years for individuals in this sample population span the years 1842 through 1910. To analyze and interpret the osteological data through an accurate contextual lens, I will use this section to provide an overview of the historical setting. I will begin speaking broadly about the United States as a whole and move narrower in scope to concentrate on the history of Northern California and Santa Clara County.

The United States, Race, and Labor Relations: A Brief History

The United States has a long history of using primarily visible traits, such as skin color and sex, to justify inequitable living conditions, labor roles, and resource access. One of the primary social tensions that structured divisions of labor in the past, and continues to have a potent legacy today, is African slavery. From early on in colonial America, light-skinned Europeans perceived Native Americans as a means to meet labor demands, and in the process of exploitation decimated their populations through the introduction of novel pathogens (Curtin, 1968; Kiple and Kiple, 1980). This, coupled with large-scale violent displays of Native American discontent, such as Bacon's Rebellion, made British colonists desperate enough for a labor force to escalate engagement in the Trans-Atlantic slave trade, despite the high mortality (15-25% per voyage) for European crews (Fennell, 2011; Smith, 2013: 33).

As colonists became more reliant on enslaved West Africans and non-white labor, Europeans worked harder to distance these same groups from resource access and the attainment of social norms. Much of this divergence likely can be attributed to the colonial perception that non-whites were just generally hardier – they were able to perform more labor, survive off less food, succumb to fewer diseases, and be less bothered by the climate. Belief in this "convenient myth" is supported by the historically widespread occurrence of nutritional deficiency in enslaved individuals in America, as well as the lack of additional clothing given to enslaved persons in the colder northern colonies (Dent, 2017; Puckrein, 1979; Washington, 2006: 43). The deaths of many of these ill-clothed northern enslaved persons, compared with general good health of colonists in the North, further indicated to the colonists that non-white skin was only suited to heat and labor. This assumed biological difference became real and embodied when colonists failed to provide warm clothes to enslaved laborers, and the differential mortality was used to reify the distinction between white and black bodies.

Slavery so deeply entrenched the view of white, masculine elitism as normative that even after the passage of the Thirteenth Amendment, laws continued to bind the bodies of the "Other" (Graff, 2015; Hartman, 1997). Pedagogical manuals, church sermons, and middle-class writings all sought to convince minority groups that laziness was sinful, but to toil was a virtue (Hartman, 1997; Kelley, 1996; Rodgers, 1979). These moral principals were used to justify the rise of the factories and a booming manufacturing sector in the postindustrial era (Healey, 2004); factories imposed hierarchies of order and supervision on the minority groups that the dominant population feared would become stagnant, idle, and a financial burden on the government (Rodgers, 1979). By the early 1900s, the United States had shifted from a heavily agrarian economy to a highly industrialized one (Shackel and Palus, 2006). With this shift came a struggle between capitalistic desires for corporate profit and worker (dis)satisfaction (Moore, 2002). Although jobs in the manufacturing sector were growing in number, they were also becoming increasingly unskilled, allowing for high labor turnover rates whenever workers decreased in productivity or went on strike (Schreuder, 1989).

Not only were patterns in labor division highly dependent on race, but they were also informed by age and gender. Children were often sourced for unskilled positions, and industrial schools were developed to "prepare" them for entrance into the manufacturing sector (Rodgers, 1979: 84; Shackel and Palus, 2006: 829). Industrial schools peaked in prominence between the mid-1800s and approximately 1920 and were primarily filled by children of the poor, particularly Native and black Americans (Charbonneau, 2023). On the other hand, while males of all ages were being taught the virtue of grueling labor, women had long been told that "anything laborious was outside a gentlewoman's 'sphere'" (Rodgers, 1979: 208). Consequently, women's labor was concentrated within the domestic realm, though most middle-class white families could afford to hire someone to handle most of the undesirable household work (Boydston, 1990; Glenn, 1992; Palmer, 1987: 182-3). Even working-class whites could often afford to hire domestic help by paying black women a fraction of what they would have had to pay white immigrant workers (Anderson and Bowman, 1953; Glenn, 1992). Black men and immigrant white men were frequently paid too little to support a family, forcing their partners and children "into income-earning activities in and out of the home," bucking social norms and further marking them as the "Other" (Kessler-Harris, 1982; Glenn, 1992: 4).

Up until World War I, when immigration rates plummeted, female European immigrants constituted the majority of domestic laborers (Glenn, 1992; Harzig, 2017). As this preferred source of domestic servants became increasingly limited, black women and other women of color filled this labor void (Palmer, 1990: 12; Glenn, 1992). According to Healey (2004: 80) and Geschwender (1978: 169), over half of black Americans remained in agriculture, but more than a fourth were employed in domestic occupations by 1910. However, also at the turn of the century, white middle-class women were looking to escape the "feminine suffocation" of the domestic sphere (Rodgers, 1979: 196). Prior to the disruption of the "Old Order" by the shifting labor needs of WWI, the woman's "place" was considered the church, home, and/or school (Gavin, 1997). With many men drafted and a new occupational need felt, single women flocked to manufacturing positions as a form of rebellion, though many were coerced into leaving these positions upon marriage (Rodgers, 1979: 196-9; Ruggles, 2015). Though more clerical roles were available to women in the early 1900s, most employed females remained in manual occupations (Rodgers, 1979: 204). Women of color in these same labor sections were relegated to the least desirable, least healthy, and lowest paying positions (e.g. Kelley, 1996). It is notable that women of color had been involved in the workforce long before white women entered en masse; this was not seen as violating "Old Order" femininity because these expectations were for *normative* groups, a label that could not be attained by non-native whites (Weiner, 1985). Women used the beginnings of newly discovered financial freedom, and the spotlight attracted by white, middle-class women laboring, to increase the pressure for suffrage (Fara, 2018; Weiner, 1985).

The purpose of providing this background is to demonstrate that although there have been shifts in labor patterns throughout American history, overarching trends remain the same. Slavery established race relations that were folded into legislation and interpersonal relationships for generations to come. Persons of color and minorities remained seen as backwards, deviant, and unable to efficiently provide for themselves, and were therefore marginalized in the labor force. Although European immigrants experienced some degree of this same treatment, privilege transcended class and ethnicity as white persons banded together to exclude black individuals from becoming a strong source of job competition. Demographic factors, such as sex and race, largely influenced occupation, which in turn determined how each individual was moving during a substantial portion of the day and for how many hours they labored. Beyond labor, these same factors shaped access to nutrition, medical treatment, and other elements that shaped their osteological components, including the knee. Understanding the nexus between social context, resources, and labor patterns is crucial to analysis of individual- and population-scale biological trends at the knee in the late 1800s through early 1900s in America.

A Narrower Scope: California History and the Santa Clara Valley

The “Mexican Period” in the Santa Clara Valley spanned the years from 1810 to 1848. Twelve years after Mexico had won its independence from the colonial power of Spain in 1821, Mexico’s Congress of the Union passed the Mexican Secularization Act of 1833. This decree transferred ownership of California missions from the Catholic Church to the Mexican authorities, as well as cast out the friars (Bright, 2019, Garcia, 1997). Although the intention of this act was to return land to indigenous Native Americans, particularly those who had been inhabiting the missions, this purpose only made up a small portion of the land grants that ensued. Most of the land was either sold for profit or given as large parcels called *ranchos* to *Californios* who had ties to those in power (Ryan and Breschini, n.d.). This left a large population of Native Americans landless and a source of cheap labor to work the newly privatized lands.

Thirteen years after the passage of the Mexican Secularization Act, California became embroiled in the Mexican American war. This war lasted less than two years and was resolved with the signing of the Treaty of Guadalupe Hidalgo in 1848, in which Mexico ceded approximately fifty-five percent of its territory, receiving at least $15 million from the U.S. as a form of compensation (Treaty of Guadalupe Hidalgo, 1848). Mexicans in the annexed areas had a choice before them: they could either relocate within the new Mexican boundaries or they could remain where they were and receive full American citizenship. In either case, the practically overnight change in their country/place of residence and the decision of whether to move or remain likely caused many to reconfigure their ethnic identities (Bright, 2019: 43). Despite many Spanish-speaking individuals being born in California, white-presenting Californians treated them as foreigners indistinguishable from more recent Mexican immigrants and coerced their land from them, forcing them into the dangerous mining industry (Bright, 2019; Prince-Buitenhuys, 2016). *Californios*, the Spanish-speaking California residents, had the power of the law on their side, which decreed the segregation of Mexicans illegal. Despite this, public sentiment upheld de facto segregation by preventing them from accessing certain jobs, voting for policies that kept them out of "white" jobs and neighborhoods, and otherwise marginalizing them in the public spheres of school, work, and leisure (Haas, 1995).

At the same time as negotiations were proceeding between Mexico and the United States, and nine days prior to the signing of the treaty, California experienced a gold strike that brought many to the foothills of the Sierra mountains (Bright, 2019; Garcia, 1997; Pitti, 2002). The incredible influx of foreigners hoping to "strike it rich" caused, in the manner of Newton's Third Law, an equal but opposite reaction in a rapid depopulation of the Santa Clara Valley area (Bright, 2019). However, these individuals were soon replaced by those who had struck out in the mines but chose to remain in the valley and try their hand in the agricultural business. The Santa Clara Valley, located slightly south of the San Francisco Bay and nestled between the Santa Cruz and Diablo Mountain ranges, quickly earned the nickname of the "Valley of Heart's Delight" due to its fertile soils (Bright, 2019). According to Zavella (1987), the prevalence of dense wooded areas in the Santa Cruz mountains blocks overwhelming humidity but permits a cool climate to persist, allowing for the Santa Clara Valley to become one of the largest fruit producers around the globe by 1869 (Bright, 2019).

The signing of the Treaty of Guadalupe Hidalgo heralded what would later be known as the "American Period" in California (everything post-1848). The beginning of this period was characterized by rapid population growth of the entire Bay Area, largely because San Francisco contained the port closest to the Sierras where gold was found (Cole, 2018). The initial wave of hopeful miners to the area were colloquially known as the "49ers." In 1848, President Polk made aware on a global scale the discovery of gold in California, leading to increased migration of individuals from Germany, Ireland, Japan, China, and South America (Prince-Buitenhuys, 2016). This migration experienced an additional boost post-induction of California into official statehood. The Bay Area suddenly found itself home to many miners, individuals involved in the shipping industries, and journalists, and by the 1860s boasted approximately one-third of the state's entire population (Cole, 2018; Mink, 1986).

By 1850 in California, the population was over ninety-percent male, and relatively young, with many men between 20 and 40 years of age (White, 1991). Despite the American idyllic image as a country made up of families, the demographics of California demonstrated this as far from actualized (White, 1991). The Bay Area's population was not much different than the rest of California – it was overwhelmingly made up of male laborers, and by 1871, desperate workers outnumbered available jobs by a factor of 4:1 (Eaves, 1910; Mink, 1986). However, the makeup of the primary labor industries was shifting. By 1865, too few had gotten lucky in the mines or had recognized its dangers (one in twelve did not make it out alive) (Starr, 2007) and laborers began flocking to the city proper in search of alternative employment (Mink, 1986).

The ethnic demographics of the Bay area were in constant flux, as the construction of the transcontinental railroad employed many white and Chinese workers, many of whom settled in the Bay Area after its completion in 1869, and many other immigrants were able to travel overland more easily to the West with the use of it (Mink, 1986). Most of the immigrants flocking to California primarily came from Germany, Great Britain, and Ireland (Prince-Buitenhuys, 2016). A majority of these immigrants found it easy to assimilate in California. This was likely due to their tendency to employ stepwise migration from the eastern coast that allowed for at least partial language and culture acquisition along the way (Barkan, 2007; Prince-Buitenhuys, 2016). It is important to note that the category of "whiteness" seems to have been more inclusive in California than on the East coast, with even the oft-disparaged Irish able to access and employ its privileges (Herbert, 2018). Irish immigrants were widely able to achieve esteemed social positions in the Santa Clara Valley and the surrounding Bar Area despite the animosity they faced on the eastern seaboard (Prince-Buitenhuys, 2016). In contrast, there was a strong and continued antagonism in the West towards Chinese people in any social or occupational capacity (Mink, 1986). This may be explained by their more identifiable physiological features and relative prevalence that made them appear a threat in the form of job competition. In the 1850 U.S. census, immigrants to California from Ireland numbered 3,848 individuals, compared to a modest 460 from China (U.S. Census Bureau, 1853). The next census (a decade later) illustrated an incredible demographic shift, with the number Irish immigrants living in California reaching 31,423 and number of Chinese immigrants nearing 34,500 (U.S. Census Bureau, 1864). Thus, likely it was not only the ubiquitous presence of Chinese individuals, but also the astoundingly rapid pace of immigration that white individuals found intimidating and necessitating action.

Racism was more than discriminatory words or actions by the lay public: it was codified. Mining license taxes were only employed against foreigners and made it cost-prohibitive for many immigrants to remain in the mining industry (Prince-Buitenhuys, 2016). However, it was also not rare for foreign mining camps to be the subjects of looting, lynching, executions, and beating (Prince-Buitenhuys, 2016; Starr, 2007). Moreover, although the land that *Californios* received as a result of the Treaty of Guadalupe Hidalgo was supposed to be internationally recognized and protected, intimidation and unscrupulous legal tactics left most penniless and landless in the end (Prince-Buitenhuys, 2016; Starr 2007). Despite their status as American citizens, *Californios* were lumped in with other non-white immigrants in public sentiment and relegated to the roles of migrant labor, mining, and prostitution (Pitti, 2003; Prince-Buitenhuys, 2016: 58). Whites – American and immigrant alike – were determined to solidify and reify their position at the top of the socioeconomic ladder.

African Americans were also subject to the racist attitudes of California residents. Although slavery was banned upon the adoption of California into statehood, this was rarely acted upon by law enforcement and thus continued to be a major source of labor up until 1865 (Prince-Buitenhuys, 2016). Moreover, the official banning of enslavement in 1850 stirred up fear around racial mixing and the state quickly put into place antimiscegenation laws that prevented the intermarriage of white and black folk (Shah, 2001). This was later expanded to include bans on the intermarriage between whites and Chinese people in 1878 (Shah, 2001). Anti-Chinese animosity seemed to increase in intensity in correlation with their rising numbers in California. Railroad companies, such as Southern Pacific Railroad, actively recruited Chinese individuals, which resulted in over 22,000 Chinese immigrants relocating to San Francisco in the years 1868-1871 (Mink, 1986: 75). This caused an excess of labor that allowed for employers to simultaneously extend the working day while also decreasing wages (Mink, 1986). The connection between Chinese people, 13.2 percent of California's population in 1870 (U.S. Census Bureau, 1872), and lower pay and fewer job openings was not lost on whites in California who were not hesitant to print their scathing opinions in newspapers far and wide (California was also a major driver for the passage of the Chinese Exclusion Act of 1882). Ousted from many industrial and city-based positions, many Chinese found their way to the agricultural niche of the Santa Clara Valley. Although white farmers in the Valley attempted to maintain racial homogeneity by relying on their wives and children to aid in planting and harvesting, the reality was that the amount of work was too great for many small families to handle (Zavella, 1987). Consequently, by 1886, 1,600 of the 2,500 Chinese individuals in Santa Clara County were involved in agricultural work in some capacity (Zavella, 1987: 483).

Recall that by 1871, the Bay Area was overrun by able-bodied men who outnumbered jobs by a factor of 4:1. For those that were able to secure work, few labored in the same position year-round. Men often worked a portion of the year farming or in the mines and spent a season working in the city as wage laborers (White, 1991). There was a clear idea of what "white-man's work" was, and it did not constitute activities such as laying track for railroads, widely understood to be a "bottom-tier job" (White, 1991: 282). While white men would occasionally occupy these positions, particularly Irish men, they were bestowed with the privilege of social mobility, which allowed them to move fairly quickly to other jobs, an experience out of the reach of Mexican Americans and Chinese (White, 1991). I suggest that the general acceptance of Irish immigrants as "white" in the Bay Area is due to the relative diversity of San Francisco. By 1870 (Ninth U.S. Census), half of San Francisco's population was foreign-born, exceeding prominent magnet cities such as New York, Boston, and Chicago (Logan, 2015). In San Francisco, 41% of that foreign-born contingent originated from Ireland. Should white Americans exclude Irish from the label of "whiteness," they could potentially be outnumbered and lose their peak social standing. It seemed mutually beneficial to bring the Irish into the fold and solidify a singular top-tier stratum.

For men working in manual occupations, a six-day, forty-eight-hour workweek was standard. For many union jobs, the daily pay rate was somewhere between \$3-\$4 with a \$5 rate being achieved by particularly useful and specialized trades such as bricklaying (Knight, 1960). Working in the metal trade was particularly harsh, as both skilled and unskilled workers were expected to labor for 10 hours per day for a mere \$3.25 daily wage (Knight, 1960). It is notable that a number of industries employed "helpers" or apprentices who were paid a fraction of the daily wages of full-fledged employees (Knight, 1960: 2). The Bay Area also boasted a large need for unskilled heavy labor, which often encompassed the most dangerous positions, that paid a measly $1.74 to $2 per day (Knight, 1960).

For women, employment trends looked quite different. In 1880, only approximately 10 percent of women between the ages of 20 and 50 were employed at all (White, 1991). For married white women, taking on any work for pay outside the home was incredibly rare, but it was not beyond the realm of possibility for them to house boarders or take in laundry from other families (White, 1991). For married women from minority groups, it was much more likely that they would be involved as domestic laborers in other households or laundries (White, 1991). The stigma around working as an unmarried woman was significantly less, and many found positions as teachers, seamstresses, domestic servants, and prostitutes. In fact, in the American West, prostitution was a prolific enterprise, with over 50,000 prostitutes working in dance halls and saloons (White, 1991). Despite the apparent dangers associated with prostitution, domestic servitude seemed the position held in the lowest regard by the women in California, likely due to its intense restriction of one's agency and other unfavorable working conditions. For this reason, domestic servitude roles, though plenty, were left to the newest arrivals and non-white women (Coser, 1973; Glenn, 1980).

By the beginning of the 20th century, San Francisco's demographics were changing once again. By this time, most local segregation laws had been abolished and, in stark contrast to the middle and eastern U.S., black individuals could exist in the same public spheres of restaurants, schools, and transportation as white individuals (Broussard, 1993). Even Los Angeles lagged behind San Francisco and continued to uphold de facto segregation, keeping black individuals within “well-defined communities” (Broussard, 1993: 2). In fact, by 1900, San Francisco had become the premier location for black individuals in California to excel socially, culturally, and politically (Broussard, 1993). However, the Santa Clara Valley lagged behind its geographic neighbor in terms of social progressiveness and industrialization. While San Francisco was cementing its dominance as the “U.S. gateway to the Pacific” with the opening of the Panama Canal (Cole, 2018), Santa Clara Valley had two primary concerns: (1) managing a second wave of migration and notable U.S. military presence due to another gold rush, and (2) finding enough labor to help with continued expansion in planting, harvesting, and processing agricultural work (Bright, 2019; Tsu, 2006). Despite relentless efforts to keep farming limited to the ‘right kind of men’ (Tsu, 2006: 479) – meaning white, family men – orchards and farms were constantly filled with Chinese workers. These workers were not oblivious to the extent of their labor power; by the 1940s, California had a greater Asian population than the entire rest of the U.S. (Bright, 2019; Commonwealth Club of California, 1946; Coolidge, 1909; Pfaelzer, 2007). More than once in the late 1800s, these workers went on strike to win better pay and working conditions from their employers (White, 1991). Although San Francisco and the greater Bay Area have historically been incredibly diverse, nativism and xenophobia still were manifest. These predispositions extended beyond foreigners. The Great Depression and Dust Bowl sent many westward seeking economic relief, only to be greeted by Californians that saw them as a burden to state resources such as healthcare and housing (Bright, 2019; Jamieson, 1942). Californians in power were ready, yet again, to weaponize their ideas of the "Other" as lazy, undeserving poor, and unnecessary job competition.

2.4 CONCLUSION

Many of the individuals in the UISC were not born in Santa Clara County. They migrated from other parts of California, the rest of the United States, and a wide range of countries. When they arrived in Santa Clara County, and more broadly, the greater Bay Area, they entered an unusually diverse community. Despite it being home to individuals of many nations and all walks of life, people in this region still found themselves arranged into a fairly rigid social hierarchy. Unique to the West, however, seems to be the relative ease in which Irish immigrants were able to assimilate into the American idea of "whiteness" and capitalize on the privileges offered, such as social mobility. Black individuals, though possessing more rights and opportunities than in other parts of the country, were still a focus of discrimination, but Chinese and Japanese immigrants appeared to bear the brunt of racial animosity. *Californios* and Native Americans were also oft-maligned and the targets of land-stealing ruses, but were not as publicly humiliated and shamed in popular media outlets as Asian individuals.

Biopolitics is key to understanding racial relations in the greater Bay Area. Though the Mexican Secularization Act was born from and endorsed by the Mexican government, U.S. officials chose not to ensure that land was transferred to the hands of indigenous people, such as the Ohlone, within the mission system as a form of reparations. This largely left indigenous individuals homeless and with little choice but to subject themselves to the exploitation of acting as cheap labor for the next owners of the newly privatized land. Although the Mexican government outwardly demonstrated realigned priorities and a position of remorse, the lack of actual enforcement left the situation unchanged with the exception of a slight shift in the group in power. But not all marginalization occurs on the State level. Following the signing of the Treaty of Guadalupe Hidalgo, the segregation of Mexicans (a category that *Californios* also seemed to fall into, despite their status as American citizens) was illegal. However, micro-level (i.e., regional-level) biopolitics in the U.S. used race as an unspoken basis to exclude Mexican individuals from accessing a swath of work, education, and governmental opportunities.

Biopolitical wars were also waged through narratives. Governments and corporations, such as railroad companies, actively recruited immigrants to come to the Western frontier. Promises of the land of gold, jobs, and plenty were dangled like an enticing carrot. The endgame of these entities was far from altruistic. They did not intend to create a multicultural city that might bring the West into a new progressive era, nor did they intend for these immigrants to actually find financial stability and community. They merely sought expendable bodies that could fill a gaping labor deficit for cheap. Corporations had little concern for how these bodies would be regulated once they arrived. The enactment of a foreign miners' taxes and California's championing of the Chinese Exclusion Act demonstrated that America's penchant for "Othering" and creation of an Us/Them divide would independently maintain an exploited underclass for continued cheap labor. Narratives of Chinese as worthless, stupid, and lazy were popularized in historical newspaper and other media outlets and spurred violent actions by white boots on the ground.

The way that biopolitics legislates whose bodies count and whose do not is a two-pronged approach – it includes both formal governmental regulations and informal means, such as lack of enforcement of reform measures, popularization of slander, and intimidation by community members. Biopolitics and the use of biopower are the means through which individuals are rendered fully or partially legible by the State. For instance, individuals seen as fully American, synonymous with whiteness at the time, were able to vote, be active leaders in the community, and achieve the highest paying jobs. White individuals in power structured the entire socioeconomic system to keep other whites in power and solidify the homogeneity of this social stratum. However, the immense need for labor as the transcontinental railroad was under construction, Santa Clara Valley was expanding agriculturally, and San Francisco was industrializing, necessitated a dramatic and rapid increase in labor-capable bodies. As a result, the State needed to let non-white bodies be legible, but *only to a degree*. Immigrants were discussed in primarily economic terms – how much would they cost employers per day? Would they be a burden on healthcare or housing resources? Would they pay taxes or evade them? The State needed immigrants to be legible just to the degree that it could ensure it was not incurring losses, but certainly not enough so that they might gain any real power.

Chapter 3: The UISC Skeletal Collection and Grappling with Ethical Implications

3.1 INTRODUCTION

The geographic and temporal focus of this research is the mid-1800s to mid-1900s Santa Clara Valley, part of the South Bay Area of California (Fig. 3.1). Osteological data were collected from the University of Iowa-Stanford (UISC) anatomical collection. This collection was chosen due to the extensive demographic information available for individuals within the collection which includes, but is not limited to, age, sex, date of death, cause of death, occupation, birth location, and in some cases, medical history. These data are crucial to understanding an individual's socioeconomic status and therefore provide some contextualization regarding life experiences. Although other collections of similar historical context and preservation level exist (Table 3.1), the UISC was chosen because it has been the subject of far fewer research inquiries. Thus, while pursuing answers to my own

Figure 3.1. *Santa Clara County is located in the South Bay Area of California, near the large cities of San Jose, Oakland, and San Francisco.*

research questions, I will also contribute valuable information to the holding institution regarding the skeletal collection.

Table 3.1 *Comparison of UISC with similar anatomical skeletal collections.*

Collection	Affiliation	Location	Dates represented	Sample Size (n)*
Robert J. Terry	Smithsonian Museum of Natural History	Washington, D.C.	1828-1943 (birth year)	1,602
W. Montague Cobb	Howard University	Washington, D.C.	1931-1935 (year of death)	634
Hamann-Todd	Cleveland Museum of Natural History	Cleveland, Ohio	1928-1938 (year of death)	3,324
UISC	University of Iowa	Iowa City, Iowa	1842-1910 (birth year)	230**

**Sample size indicates the number of individuals over the age of 14.*
*** Although the UISC contains the remains of about 1,100 individuals, only 230 of those have associated documentation.*

3.2 HISTORY OF THE UNIVERSITY OF IOWA-STANFORD COLLECTION

The UISC was previously known as the Stanford-Meyer Collection (S-MC) – named after the man responsible for its inception, Dr. Arthur W. Meyer – and was held at Stanford University's School of Medicine. All individuals in this collection are alleged willed donations from between the 1920s-1950s, and the collection is now housed at the University of Iowa Office of the State Archaeologist (Eaves-Johnson, 2004). Skeletal remains in the S-MC were used actively until the 1970s, at which point heavily damaged remains were removed from the collection (Eaves-Johnson, 2004). Extensive earthquake damage at Stanford's Anatomy building led the department to look for alternative storage solutions, an issue which was solved when Dr. Robert Franciscus arranged for its transfer to the University of Iowa Office of the State Archaeologist in 1998 (Eaves-Johnson, 2004). Although once stored in an underequipped basement in cloth bags, individuals are now housed in an environment (still a basement) with humidity control and in well-labeled, new white boxes.

Educational materials distributed about the UISC teaching collection indicate that while the collection is comprised of approximately 1,100 individuals, only 230 are associated with related documentation and these individuals are the subsample of focus in this dissertation. In this instance, documentation refers to written evidence of legal name, place of birth, dates of birth and death, ancestry, sex, age, occupation, cause of death, length of residency in the country and state of California, and marital status. The length of residency in California is noted because these individuals worked and died in the San Francisco Bay area, but often originated from another location. The duration of stay in the United States is recorded because much of this sample population represents European immigrants who arrived in California sometime between the late nineteenth and early twentieth centuries.

Many of these skeletal remains were utilized as medical teaching specimens from the 1920s to 1950s, and therefore many elements bear cut marks from dissection and some skulls have sustained extensive damage, especially in the facial region (Eaves-Johnson, 2004). The damage does not significantly impact this project, however, as long bones largely managed to escape with little destruction, and cranial and postcranial nonmetric traits will be used in conjunction for biodistance analysis. Demographics of this collection will be covered in-depth later in this chapter, but broadly, the documented sample of this collection is heavily weighted towards males (n=198, females n=31).

Males represent an age range of 27-96 while females span a slightly older average age range of 46-91. Overall, this collection is biased toward older, edentulous individuals.

Provenience

The individuals that make up the UISC came from local alms houses, hospitals, and asylums when individuals could not afford burial rites or lacked family willing or able to claim the bodies after death. Documentation points to five specific institutions that contributed to the sourcing of bodies for this anatomical collection: Santa Clara Almshouse, Santa Clara Infirmary and Almshouse (now the Santa Clara Valley Medical Center), the City and County Hospital of San Francisco, Laguna Honda Home, and Agnews State Hospital (also known as Agnews Insane Asylum). Almshouses were institutions where the destitute poor or chronically ill could reside when they had nowhere else to go.

The Santa Clara Almshouse was promoted as the "finest almshouse in the world" by local San Francisco media outlets (San Francisco Call, 1896). Before it became a public-serving institution, it was one of the largest and most opulent residences in all of California. It previously belonged to John O'Toole and his family, but quarrels divided the family into factions and tensions rose to involve physical altercations while money dwindled (San Francisco Call, 1896) (Fig. 3.2). The cost of upkeep drove O'Toole into debt and the 100-acre property stood vacant until it was purchased in 1884 by Santa Clara County for $15,000 (San Francisco Call, 1896). In the late 19th century, the almshouse housed 150 residents ("inmates") aged 65-95 only one of which was female and who was there accompanied by her husband. Although females were not restricted from living in this almshouse, a 1910 Census report on “paupers in almshouses” found that all 195 residents in the Santa Clara Almshouse were male. Once again, no records indicate the exclusive nature of the almshouse, but it also seemed to cater heavily to whites, with zero residents of color in 1910 but anecdotal evidence of Hispanic residents in prior years (San Francisco Call, 1896; U.S. Census Bureau, 1913). However, there was a very even split between native- and foreign-born white residents, partially reflective of the diversity within the larger community.

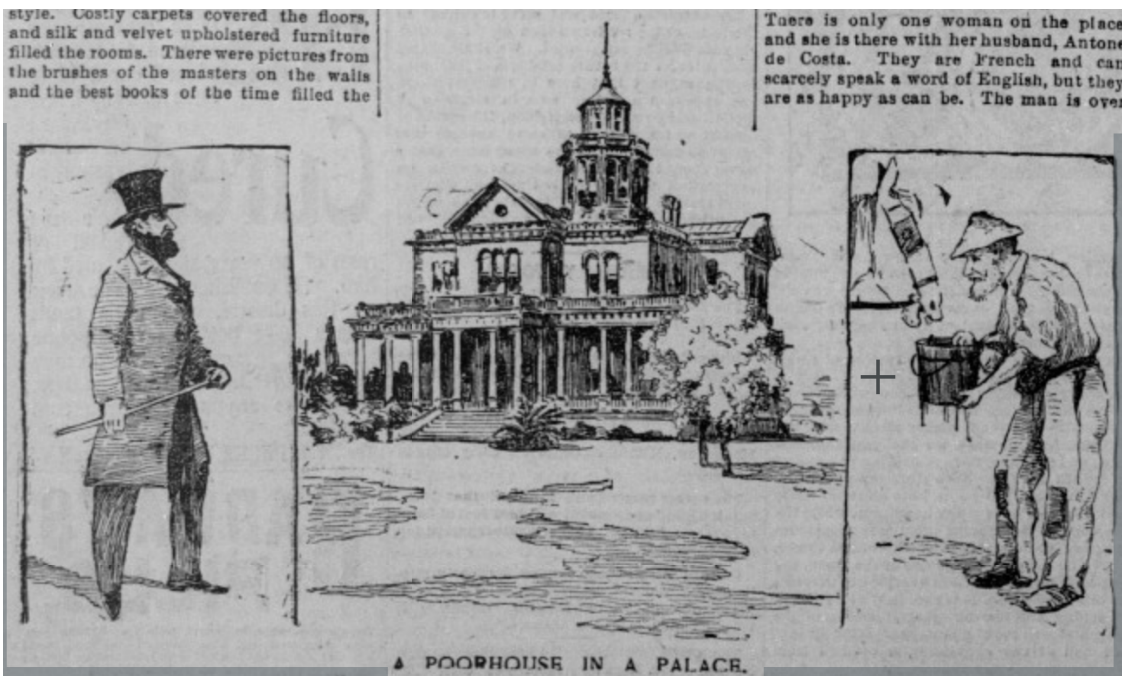


Figure 3.2. *Illustration featured in the San Francisco Call in 1896 depicted John O’Toole before and after he became destitute, and his mansion that became the Santa Clara Almshouse.*

Santa Clara Valley Medical Center was built specifically for the indigent community and had multiple departments within that allowed it to simultaneously serve as an almshouse, senior care facility, and medical center. For this reason, it was originally referred to as the Santa Clara County Infirmary and Almshouse (Fig. 3.3). It existed entirely as a temporary structure from its inception in 1855 until the laying of a permanent foundation in 1863 (Prince-Buitenhuys, 2016). The earliest functions of this facility were medically centered, with the almshouse not established until 1900 (Prince-Buitenhuys, 2016: 65). Although the almshouse population was primarily made up of white individuals, in contrast to the Santa Clara Almshouse, its "white" population was also almost entirely foreign-born (Prince-Buitenhuys, 2016; U.S. Census Bureau, 1913). By the 1930s, the almshouse was caring for approximately 400 individuals daily, and the high degree of fluctuation in its reported population is indicative of high turnover rates (Prince-Buitenhuys, 2016; U.S. Census Bureau, 1906). Though unable to determine the sex ratio of residents at this specific almshouse, of the 8,330 paupers admitted to almshouses across California in 1904, 7,338 of these individuals were men and it is likely a safe assumption that this trend described the Santa Clara Infirmary and Almshouse as well (U.S. Census Bureau, 1906:120).

Figure 3.3. *Santa Clara Infirmary and Almshouse illustration from David Rumsey Map Collection.*

The histories of the City and County Hospital of San Francisco (CCHSF) and the Laguna Honda Home (LHH) are intertwined through disaster and disease. The Laguna Honda Home (Fig 3.4) was built first in 1866 to help care for the gold rush pioneers, or more specifically, those who failed to strike it rich. The land upon which LHH would be later built was the former rancho of the last mayor of San Francisco when it was still part of Mexico (City and County of San Francisco, n.d.). Upon the land was built a four-story wooden building that would house its residents, and the 87 acres of arable land were used to grow produce to feed its populace. Enough surplus was grown that by 1870, not only was the almshouse feeding a population of over 500 people, but they also gave the residents food to sell at the market as a way of "earning their keep" (City and County of San Francisco, n.d.). The LHH received its first building solely dedicated to medical care in 1868 as a response to a smallpox epidemic, but once cases began tapering off, this small infirmary was transitioned into an asylum (City and County of San Francisco, n.d.). In the late 19th century, the LHH was home to people from at least forty different countries. In 1906, when the great earthquake and fire of San Francisco was followed shortly by an outbreak of bubonic plague, the CCHSF, dilapidated and overrun with cockroaches and rats, was unequipped to handle

Figure 3.4. *Laguna Honda Home circa 1890, courtesy of Open San Francisco History.*

this spike in displaced persons (Eloesser, 1969). Many were transferred to the LHH which was now housing San Franciscan refugees and adopted the name of the "Relief Home." To house this influx of people, Clarendon Hall was built on the premises in 1910 and its purpose was specifically to provide long-term medical care to those who needed it (City and County of San Francisco, n.d.). By 1918, the new CCHSF building had finished construction, and residents were able to transfer back. Fewer than ten miles separated these two facilities. The LHH straddles the line between medical care center, almshouse, and asylum, and it is difficult to find a clear demographic report of patients/residents at either facility during this time period.

Agnews State Hospital is also referred to as Agnews Insane Asylum and Agnews Residential Facility. It broke ground in 1885 and opened its doors to neuropsychiatric patients by 1889, specifically catering to those who were deemed mentally ill (National Parks Services). Construction of this facility cost approximately $750,000 and earned it the title of the "Great Asylum for the Insane" (Pearce, 2013). In 1906, during the great earthquake, the reinforced building crumbled, killing over one hundred patients and staff and resulting in the single greatest loss of life during this natural disaster (National Parks Service, 2018). It was rebuilt and resumed activity under the name Agnews State Hospital. It was lauded as the first "modern mental hospital" in California, boasting architectural features that allowed plenty of natural light, fresh air, and hopefully, cheer (National Parks Service, 2018). In 1910, Agnews had 698 residents, 410 males and 288 females (U.S. Census Bureau, 1913: 8). Of these individuals, 322 were white American-born, 336 were white foreign-born, and 15 were described as “colored” (U.S. Census Bureau, 1913: 8).

Taken as a whole, the demographics of these institutions explain the biases in the UISC collection towards older white, male individuals. A peculiar phenomenon of note is that despite none of these institutions barring women from entrance, they are sparsely represented. I suggest that when women were seen as needing care and incapable of independence, they experienced a greater instance of being taken in by relatives, friends, or others in the community. Men, on the other hand, were expected to be providers and independent. It would be less likely for others to offer help, and more demeaning for men to live with relatives. Perhaps they saw entrance into almshouses as retaining a degree of independence when compared to staying with relatives or friends. It is also worth noting that so few people of color were members of these types of institutions when the populace of Santa Clara and San Francisco counties were relatively diverse. It is unclear whether persons of color were generally unaware of the existence of these social safety nets, were turned away at the door due to perceptions of them as “undeserving” poor, or chose to stay away, maybe because of a distrust of government programs and aid. Historical sources such as newspaper articles do not reveal any possible obvious animosity towards persons of color in hospitals, almshouses, or asylums.

3.3 CONSIDERATIONS OF STUDYING AN ANATOMICAL TEACHING COLLECTION

The skeletal collection of focus in this dissertation is the University of Iowa-Stanford Collection (UISC). Like the Hamman-Todd, Robert J. Terry, Huntington, and

William Montague Cobb collections, the UISC served as an anatomical teaching resource. All of these collections share one important similarity – they are filled with 19th-century remains of almshouse residents, immigrants, psychiatric patients, the poor, and the unclaimed (de la Cova, 2011; Cobb, 1935; Hunt and Albanese, 2005; Nystrom, 2014; Watkins, 2012). The same groups that were marginalized and excluded from society during life were "collected" and coerced into giving up bodily control even into death. This section considers these anatomical skeletal collections as an example of postmortem structural violence, grapples with the ethical considerations of their use, and presents a set of recommendations for best practices moving forward.

Defining Structural Violence

The term structural violence was first used by Johan Galtung (1969) to refer to inequalities in resource access created by power differentials. A group in power can structure resource access to create a hierarchy of privilege. The category of "resource" can refer to anything from money to food to health access. Galtung argued that the establishment of a funnel of access was not only a social injustice but constituted a form of violence on the disenfranchised groups at the base (Tremblay, 2017). Paul Farmer (2004) filtered this concept through an anthropological lens to include dialogues of political economy and culture and added an emphasis on situating present injustices within the context of historical processes (Farmer et al., 2006; Nystrom, 2014). Farmer also revolutionized the term by demonstrating that structural violence was not limited to interactions between living individuals but could be expanded to include relationships between the dead and the living (Watkins, 2018b). The anatomical skeletal collections discussed in this paper are one example of living persons exploiting and enacting harm upon deceased individuals.

Klaus (2012) and Nystrom (2014) were pivotal in the process of applying the concept of structural violence to archaeological pursuits. These authors argued that differential resource access becomes embodied; level of privilege and marginalization then manifest in skeletal differences (Nystrom, 2014). In other words, experiences of structural violence are written into the biological elements and detectable by researchers. How I employ structural violence in my research, however, sits at the nexus of Farmer (2004), Klaus (2012), and Nystrom (2014). My research both centers the premise of biological differences due to social inequalities, as well as grapples with the ethical conundrums of studies of deceased persons who may or may not have consented to postmortem use of their bodies. Thus, I build on Farmer's argument that structural violence can be exhibited by the concentration of harm on groups of deceased individuals, while also referencing the embodiment of structural violence in my interpretation of osteological data.

Structural violence as a concept does not constitute a theory as it is merely descriptive, but it can become an analytical framework when combined with historical context (political, economic, social) to provide it explanatory power (Martin et al., 2013; Tremblay, 2017). Use of a structural violence framework validates embodied harm that may have been normalized, "invisible," or unintentional, but real nonetheless. Use of a structural violence framework also challenges the assumption that harm can no longer be experienced after death and disrupts the tradition of skeletons-as-objects archaeological perspectives typically possess.

Origins of Individuals Populating Anatomical Collections

The American legacy of manipulating and exploiting bodies of the Other has roots in traditions of dissection laws. Dissection has a long history of being meted out as a punishment for crime or for existing as the undeserving poor (Hildebrandt, 2008; Nystrom, 2014; Richardson, 1987; Sappol, 2002). Dissection persisted as punishment for centuries because of widespread religious beliefs that considered incomplete bodies as ineligible for resurrection during the Second Coming (Bynum, 1995; Zimmer, 2018). Even those without religious fervor seemed to share an understanding of reverence for the deceased and a taboo against any postmortem slight that damaged the integrity of the individual's identity (Nystrom, 2014).

Although dissection laws had a lengthy history in Europe dating back as early as the 1500s, the first American version of this punishment was not written into law until 1789 (New Jersey) and allowed judges' discretion to add dissection as a supplementary punishment when seen as fitting (Muller et al., 2017; Nystrom, 2014; Sappol, 2002). During the 1800s, the number of established medical schools continually increased and demand for teaching cadavers could not be met through dissection laws alone (Nystrom, 2014). The insufficient supply of legal, if immorally obtained, cadavers created a ripe opportunity for the formation of a black market. This hole was filled by "resurrection men," or graverobbers who unearthed freshly interred bodies and sold them to medical schools. However, not all graves were violated with equal frequency. Black cemeteries were overwhelmingly the targets of resurrection men, though the graves of poor white persons would also suffice (Washington, 2008). Resurrection men reigned until the body of a white mother in New York, buried only a few days before, was discovered in a dissection theater by her child who had snuck in (Wilf, 1989; Zimmer, 2018). As a response, cities began passing laws prohibiting the work of resurrection men which limited, but did not all together eradicate, the illicit economy of medical cadavers.

As local legislatures were working to gain a handle on (white) graverobbing, alternative avenues for obtaining the bodies of the deceased were created by adding laws that gave medical schools the right to dissect any unclaimed bodies (Nystrom, 2014). The first of these laws was passed in Massachusetts in 1831 and legalized the automatic transfer of unclaimed decedents to anatomy programs (Muller et al., 2017). Residents of almshouses were particularly common targets of this kind of legislation as they were divested of power, had no family or were socially abandoned, and therefore could not effectively fight postmortem use of their bodies (Nystrom, 2014).

Broadened use of dissections as punishment was justified to whites as a mechanism for preventing graverobbing, but in reality, these laws were implemented as social control methods to warn or deter people from becoming a burden to society as a criminal or indigent (Nystrom, 2014). While not explicitly discriminatory, dissection laws, working in conjunction with the violence of slavery, did land a disproportionate number of African American bodies on dissection tables. Not only did African slaves have to fear experimental and voyeuristic surgeries in front of audiences, but even freedmen had to fear ending up on the same table in the medical theater (Washington, 2008). In academia, when “publish or perish” was (and is) king, the pages of academic journals were filled with images, diagrams, and data collected from the bodies of African Americans (Washington, 2008). According to Washington (2008), black persons were the most popular dissection targets because they were considered unilaterally willing, or at least unable to dissent. Moreover, who would speak up or riot when they saw a black body on the dissection table?

By the 1900s, most states passed legislation allowing for persons that were wards of the state in any capacity – from poor farms to sanitariums and city hospitals – to be claimed by medical schools after a specified amount of time had passed and no relatives had come forward (de la Cova, 2019). Despite the “neutral language” of the new laws, no large-scale changes in cadaver demographics occurred as it “simply assured that cadavers would come entirely – rather than primarily – from American’s lowest social strata” (Humphrey, 1973: 824; Muller et al., 2017). Shifts in cadaver origins only truly began to change with the inception of willed body laws when individuals could promise their bodies to scientific or medical causes during life. However, even “donations” were not entirely obtained through altruistic means, as anecdotal evidence from New York recounts incidences of men waiting in hospital rooms to threaten family members with vague, nebulous lawsuits if they did not donate the body of the deceased relative (Zimmer, 2018). Victims of this coercion were those who had little money or lacked education to know that the lawsuits were nothing more than fiction. Throughout American history, medical training programs continually utilized the bodies of the poor and marginalized as the foundation of knowledge production systems. Despite revisions and new legislation, changes were only surface level and the bodies that were exploited in life continued to be exploited in death.

Anatomical Medical Collections as Structural Violence?

After dissection, the best-preserved skeletons were collected and aggregated to create osteological teaching resources. As curators across the country began amassing teaching collections, overrepresentation of the poor, persons of color, and immigrants became apparent (Muller et al., 2017). The category of "poor" also included those deemed mentally unwell and living in state institutions. Most surprising, however, is the overrepresentation of African Americans regardless of socioeconomic standing (Zimmer, 2018). Taken together, the evidence indicates that historical structural inequalities determined whose bodies were available for postmortem exploitation and who retained corporeal respect into death (Watkins, 2018b).

Some may argue against dissection as a form of structural violence because there is no similar discussion around the topic of autopsies, even though both involve postmortem manipulation of the body. The critical difference between the two, however, is intent. Undergoing an autopsy indicates that an individual is worth the time, effort, and fiscal investment into determining their cause of death (Crossland, 2009; Martensen, 1992; Nystrom, 2014; Sappol, 2002). Dissection, however, has historically meant the opposite; dissection has been an indicator that an individual did not occupy a valued societal position, and would not be missed, mourned, or rioted over by those in power when their body became part of medical pursuits.

During autopsies, great care would be taken to keep the body intact and presentable for services, but dissection was not approached with the same attitude, with practice cuts and separation of body parts a norm. Therefore, dissection violated popular Christian beliefs in the necessity of an intact body to be a candidate for resurrection upon the Second Coming and disarticulation rendering Heaven inaccessible (Bynum, 1995; Zimmer, 2018). Not only is the medical manipulation of the corpse a form of spiritual violence, but separation of the anatomical elements changes the osteological narrative (Biers, 2019): representation of an individual as a partial skeleton transmutes the individual into an object by removing their presentation of humanity. Furthermore, keeping some osteological elements and discarding others renders researchers unable to reconstruct life experiences as well as they otherwise could.

For African Americans, though, dissection carried additional weight. Because dissection historically was carried out sans consent, it became an "extension of slavery" by keeping them shackled to white control and thwarting the liberation many saw as promised by death (Washington, 2008: 129). According to Washington (2008), the bodies of African Americans on display in medical (or medical-adjacent) settings were reminiscent of the violent warnings made in the form of lynching in public places, sure to catch the eye of black "subjects" (140). The display of remains in public settings such as museums or classrooms, and encouraging researchers to engage with anatomical collections also presents the remains as perpetually "available" (Watkins, 2018a, 2018b). As entirely open access, the individuals in these collections are represented as educational objects, rather than persons, and are therefore excluded from discussions of repatriation, reinterment, or NAGPRA-esque protections (Watkins 2018a, 2018b).

Museums and educational institutions can be loci of harm for historical collections and for modern descendants. Due to the central role played by the holding institutions, many scholars recommend that it be the ethical duty of the university or museum to vet the source of the collection (e.g., Caffell and Jakob, 2019). This is not limited to checking legality of possession, but also assumes that institutions will make ethical judgements. In the process of considering the collection source, institutions are also charged with curating archival information, osteological reports, and excavation information if applicable (Caffell and Jakob, 2019).

Holding institutions have further been criticized for the uncritical use the historical racial designators found on birth and death certificates. Zimmer (2018) argues that this perpetuates "definitional violence" in which social categories are solidified through categorization (Omi and Winant, 1994). In this case, Zimmer is referring to the traditional tendency to classify any person of color under the umbrella term of "Negro" while having a diverse array of terms to identify different types of whiteness (Zimmer, 2018). To not challenge, or at least offer a caveat, when using these racial terms affirms traditions of treating white persons as the normative group worthy of recognition, while everyone else exists as outside the norm and is only worth homogenization.

One of the most difficult issues for anatomical collections to contend with is their participation in "osteological subject making" (Spillers, 1987; Spillers et al., 2007; TallBear, 2014; Watkins, 2018a). Osteological subject making refers to the use of

Othered persons to serve as the basis for knowledge production processes, and in normalizing this practice, treating these groups as subjects rather than once-autonomous human beings with a rich history of life experiences. Watkins (2018a: 32) argues that translating individuals into "raw material" is a form of structural violence that serves to perpetuate historical modes of harm that are rooted in labeling some bodies as valuable and others as suited for exploitation and experimentation.

Filling anatomical skeletal collections with disposable bodies who have now become osteological subjects has largely prevented curators from needing to enter discussions of protection, reinterment, and repatriation (Watkins, 2018a). More specifically, the unclaimed label given to the skeletal remains insinuates that there are no relatives, no communities that must ethically be contacted to have these difficult discussions. Scholars have begun to challenge the morality of keeping remains in classrooms, labs, and basements for an indefinite amount of time in the name of "education" (e.g., TallBear, 2013; Watkins, 2018b). For the most problematic of collections, debate regarding resolutions depends on the country of origin, with scholars in United States favoring arguments for deaccession and repatriation and scholars in Europe favoring destruction and reburial (Claes and Deblon, 2018).

According to Biers (2019), the question of how to interact with and curate anatomical skeletal collections is a point of contention due to stark differences in motivations across the holding institution, researchers, the descendant communities, and the interested public. Cultural, religious, and moral beliefs overlap and clash and navigating issues of curatorship, responsibility, and ethics can be one of the most difficult problems faced by biological anthropologists (Biers, 2019). For researchers and institutions, the act of curating human remains can transmute them into objects, while the public and descendant communities push against this to retain some aspect of humanity (Claes and Deblon, 2018; Muller et al., 2017). Watkins (2018b: 171) asserts that even when skeletal elements are objectified, it is impossible for them to be seen as "finished objects" by those who wish to study them. If osteological elements are missing, then they are incomplete; if curated objects, they are not pristine, as they have been through the transformative mechanisms of dissection and research. In other words, any alterations to the skeleton that change its preservation state are seen as hurdles to future utility.

Human remains, then, exist along a continuum ranging from incomplete object, to subject, to human. Where they fall along this scale oscillates depending on the cultural lens of the viewer. On the other hand, the observer also retains a fluid position that can range from exploiter, to voyeur, to fictive or biological kin and activist. I argue that the work of the researcher is to eliminate one end of the spectrum, that of exploiter and objectification.

Part of this work lies in passing ethical practices along to students. As suggested by Roberts (2009:17), mentors and teachers must convey to students that they should not take access to human remains for granted (Caffell and Jakob, 2019). Though anatomical skeletal collections are demographically biased and subject to the osteological paradox, they remain a strong source of knowledge regarding historical structural violence and disparities in health outcomes (de la Cova, 2011). We must impress upon students that access to this knowledge is not to be taken lightly. Despite the presentation of anatomical collections as excessively "available" for study, this does not imply perpetuity. To prevent enacting further harm, misuse of human remains must necessarily be punished through revocation of access. If we do not actively attempt to break cycles of structural violence and postmortem harm, then we do not deserve to interact with human remains. As bioarchaeologists, and more broadly as anthropologists, we are in a position to be reflexive and identify harmful methodologies. We can then respond by reorienting our interactions with human remains within a social justice perspective by exposing and acting against historical and modern mechanisms of structural violence (de la Cova, 2019; Kakaliouras, 2012; Watkins, 2018).

On Ethics and this Dissertation

Historically, individuals that fill teaching collections arrived in the United States alone, were unclaimed wards of the state, were the victims of graverobbing, or had families too destitute to afford funerary expenses. The result of society Othering these individuals, and labeling their lives as expendable, is that poor whites, immigrants, and persons of color overwhelmingly filled dissection halls and later, skeletal teaching collections. The overrepresentation of these groups presents an ethical conundrum. Because anatomical teaching collections are created through the means of structural violence – by gatekeeping resources, passing discriminatory legislation, and differentially valuing some lives over others – how can I study the people in these collections without enacting further harm? How can I approach these collections thoughtfully, respectfully, and without carrying life experiences of marginalization into postmortem existence?

Radical transparency is a mechanism against invisible violence. This begins with researchers, myself included, openly acknowledging the unethical origins of research collections. Ignoring the narrative of inception is to ignore the structural violence which paved the way for differential treatment of bodies and lives. Silence itself causes violence; silence predicates avoidance. Bearing witness, on the other hand, forces confrontation so that moving forward we – anthropologists, researchers, academics – can know how to do and be better. Radical transparency also involves the presentation of clear research questions and goals and explicates why it is that those particular goals and questions were chosen. Explicit reasoning demonstrates that I am aware of the historical use of black and brown bodies for medical experimentation, and counter notions that I will contribute to that tradition.

Providing detailed methodological outlines and rationale serve a similar purpose. For instance, in my research, I choose to characterize robusticity utilizing midshaft measurements despite a majority of research studies relying on cross-sectional measurements that often require physical cutting of the bone (or in some cases, just expensive technology). I am open about opting for noninvasive, external diaphyseal measurements because: (1) they closely approximate cross-sectional analysis, allowing me an alternative mechanism to answer my research questions and (2) to minimize harm done to individuals included in the collection, who have already been the target of enough violence (Pearson, 2000). I also avoid craniometric measurements due to the racist history of these studies designed to "prove" inferior intellect of certain races and therefore justify subjugation of and violence towards certain groups of people (Dudzik and Kolatorowicz, 2016; Hooten, 1930).

In my research, I also actively push back against definitional violence by acknowledging the difficulties of utilizing assigned racial categories listed on primary documents (Zimmer, 2018). As a different way of looking at ancestry, I instead utilize biodistance analysis to create new groups of relatedness. I argue that rather than relying on dubious racial categorizations on death certificates to define populations, the de novo construction of genetic groups allows for equal consideration of genetic variability among all groups. In other words, establishing new related groups recovers variability flattened by the catchall terms of "colored" or "white".

I have chosen my methods slowly and carefully to counter traditions of structural violence. I will put the same thoughtfulness into making available the results and interpretation of my research so that descendant communities and scholars from other disciplines are able to engage with my work and challenge any implicit biases or assumptions in my research. Publications of articles and presentations at conferences are logical initial steps of this work. I intend to engage in these avenues of dissemination beyond the field of anthropology. Historians and sociologists have also offered crucial insight into the methods and interpretations of this research, and an ethnic studies perspective is critical to discussing the concept of race in a productive way. The ethically dubious origins of this collection might serve as an illustrative purpose in workshops regarding ethical procedures in the social sciences.

Although individuals in the UISC represent a range of locations of origin, perhaps a good starting point for familiarizing people with this collection begins at its home institution, the University of Iowa. Collaboration with the Office of the State Archaeologist may allow for students to gain hands-on research experience through internship positions while also contributing to the limited knowledge about the individuals who comprise the UISC. Moreover, another future phase of this research, preferably integrating undergraduate students, includes in-depth ancestry/genealogical work. Much of the labor information for UISC individuals was sourced from documents like census records and draft cards with large amounts of time elapsing between documentation. While trying to fill in these labor gaps by tracking down more primary documentation, it may also be possible to find living descendants who may not be aware that their deceased relative is part of this collection. Finally, when further testing is completed with a larger sample size, if the results are similar, this research may move into a phase of collaboration with physical therapists to develop intervention programs meant to stabilize or enlarge the intercondylar notch space.

In my analysis and interpretation of results, I provide geographical and temporal contextualization by pulling from a variety of disciplines including American history, ethnic studies, and biomedicine. In my commitment to interdisciplinary work, I will also ensure not to relegate the skeletal collection to the realm of history by making connections to modern instances of structural violence and welcoming scholars from outside of anthropology to do the same. If I can abide by this plan for ethical research, I hope to achieve Rachel Watkins' (2018b: 171) lofty goal of providing "visibility that prevents exacting structural violence through obscuring history."

3.4 DEMOGRAPHICS

Aspects of Identity – Sex, Race, and Nation of Origin

Of the 230 individuals associated with documentation in this collection, only 186 had at least one femur present and in a state of preservation that allowed for measurements of the intercondylar notch. In this section, I will be comparing the demographics of the subsample (n=186) with the UISC sample overall to determine if those with preserved femora are representative of the collection as a whole. As previously mentioned, the UISC underrepresents females. Out of the sample of individuals with at least one femur, 166 (89.2%) were determined to be males and 20 (10.8%) females. This seems to match the characterization of the documented-UISC sample overall which includes 198 males (86.1%) and 32 females (13.9%). The overall collection is also heavily biased towards white individuals, and this continues to be the case in the sample represented here (Table 3.2). Based on this comparison, it does seem that the preservation of femora was random, and that the subsample is representative of the UISC with respect to sex and racial proportions. While ideally it would be preferable for this sample to be more racially diverse, I believe it is still possible to gain valuable insight into the etiology of the stenotic intercondylar notch and its relationship to social, economic, and other biological factors. The results of this research can serve as a comparative sample as further work is done to include other genetic populations and the inclusion of more females.

Table 3.2. *Breakdown of assigned racial categories of individuals in the UISC.*

	Documented-UISC Overall			Subsample (w/femur) Studied		
	N	Percent	Valid Percent	N	Percent	Valid Percent
Asian	13	5.7	6.4	13	7.0	8.4
Brown	7	3.0	3.4	5	2.7	3.2
Black	6	3.6	3.0	3	2.6	1.9
White	177	77.0	87.2	134	72.0	86.5
Total	203	88.3	100.00	155	83.3	100.00
Missing	27	11.7		31	16.7	
Total	230	100.00		186	100.00	

Note: *Racial categories do not represent my determinations, but the assigned racial categories listed on death certificates or mental hospital intake forms. "Asian" is a cumulation of the categories: Yellow, Chines, Mongolian, and Japanese. "Brown" includes the assigned races of "Brown" and "Mexican." "Valid Percent" denotes that those lacking assigned racial categories are excluded from the descriptive statistical analysis (i.e., only those with a value assigned to race are included in this breakdown).*

Although the UISC overall and the subsample studied here are overwhelmingly comprised of white individuals, it is important to not mistake this for homogeneity. A majority of the individuals did have their nation of birth listed as the United States, but represented all regions of the U.S. The United States is a large country that within its borders experienced, and continues to experience, regional differences in identity and social hierarchy formation, as well as variances in the meaning of whiteness. In many ways, moving from the South to the Western frontier could feel like entering a new country although no national borders needed to be crossed. For this reason, in the birth location analysis, the United States is not treated as a singular location but is broken up into smaller parts that would better represent differences in primary industries and racial/ethnic relations. The United States is divided as follows, per the categories determined by the U.S. Census Bureau:

- **West U.S.** – Washington, Oregon, California, Nevada, Arizona, Utah, Idaho, New Mexico, Colorado, Wyoming, Montana, Hawai'i
- **Midwest U.S**. – North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Indiana, Michigan, Ohio
- **South U.S**. – Texas, Oklahoma, Arkansas, Louisiana, Mississippi, Alabama, Tennessee, Kentucky, West Virginia, Maryland, Delaware, Washington, D.C., Virginia, North Carolina, South Carolina, Georgia, Florida
- **Northeast U.S.** – Pennsylvania, New York, New Jersey, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, Maine

Other nations represented in this sample include, but are not limited to, Germany, England, Austria, the Philippines, China, Ireland, and Italy.

To show the diversity of nations of origin within the UISC, I use two methods of categorization. In the first, I look at individual nations, with the U.S. still segmented into four regions as previously described (Table 3.3). Descriptive statistics indicate that the most common nations of origin seen in the UISC are (in order of decreasing prevalence): the U.S. (primarily the Midwest and Northeast), England, China, Italy, Germany, and Ireland. I believe this scheme best demonstrates the primary nationalities represented but does relegate many to the catchall category of "Other" because there are too many countries with only 1-2 individuals (i.e., these minute categories lack statistical meaning). In this scheme, the "Other" category, which consists of 16 countries not yet listed, is the second largest grouping. It is my view that this is indicative of a grouping system with low inferential power. I choose to still include it as a way of visualizing the most common nationalities represented in the Santa Clara Valley but believe that the second grouping scheme reveals more generalizable information about nation of origin.

Table 3.3. *Birth Location Scheme 1 in the UISC and subsample broken down by individual nation.*

	Documented-UISC Overall			**Subsample (w/femur) Studied**		
	N	Percent	Valid %	N	Percent	Valid %
West U.S.	22	9.6	10.2	16	8.6	9.1
Midwest U.S.	48	20.9	22.2	41	22.0	23.4
South U.S.	14	6.1	6.5	10	5.4	5.7
Northeast U.S.	25	10.9	11.6	23	12.4	13.1
Germany	11	4.8	5.1	10	5.4	5.7
England	12	5.2	5.6	11	5.9	6.3
Japan	4	1.7	1.9	4	2.2	2.3
China	12	5.2	5.6	10	5.4	5.7
Ireland	11	4.8	5.1	8	4.3	4.6
Italy	12	5.2	5.6	9	4.8	5.1
Other*	45	19.6	20.8	33	17.7	18.9
Missing	14	6.1		11	5.9	

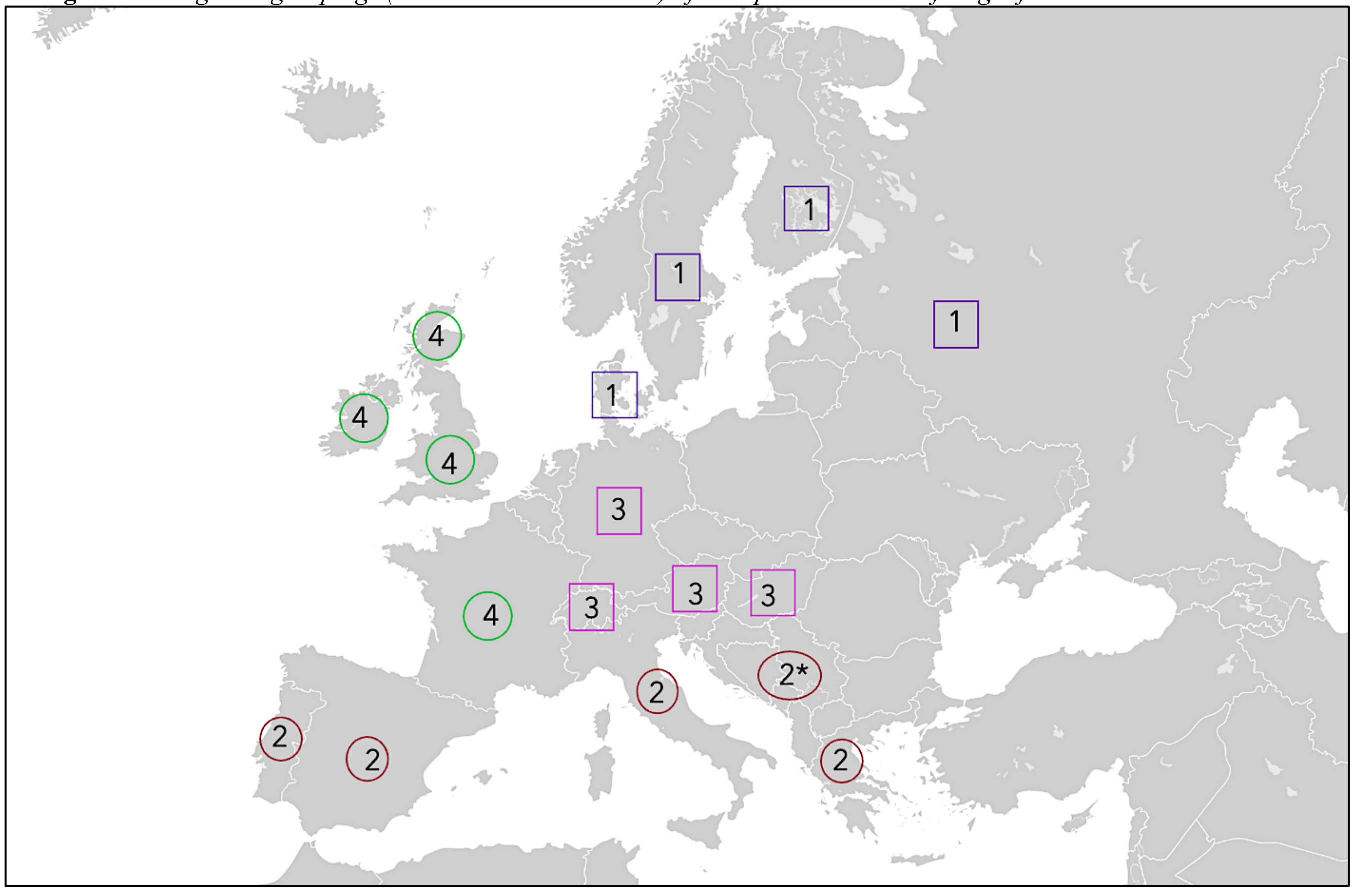
Other includes: *Switzerland, Canada, Spain, Korea, Philippines, France, Russia, Denmark, Hungary, Portugal, "Central America," Greece, Finland, Sweden, Mexico, Yugoslavia, and Austria.*

Birth Location Scheme 2 recognizes that ideologies and values do not often respect (socially constructed) borders, and bleed into surrounding areas (Table 3.4). Thus, it focuses on grouping countries together into broader regions and has the added benefit of eliminating the need for a miscellaneous "Other" category. Moreover, the regional grouping, similar to the method of utilizing birth cohorts, protects against contradiction in the documentation. For example, UISC 960, a white male born in 1891, is listed as having been born in Jersey City, New Jersey on his draft card, but the birthplace on his death certificate is referenced as New York, New York. This seems to be the only clear instance of this type of documentary incongruence with respect to birthplace in the UISC, but the fact that it exists means that it is possible that other birthplaces have been incorrectly documented. Thus, the use of global regions protects against degrees of error. Birthplace Scheme 2 also grants a better understanding of cultural diversity in the Western frontier of the United States. Using either scheme, it is clear that Santa Clara Valley became home to people from around the world and that characteristic helped shape its unique definition of whiteness and what it meant to be a "minority."

The regional breakdown in Birth Location Scheme 2 is as follows and is partially depicted in Figure 3.4:

- The regions located in the U.S. follow the same breakdown as Scheme 1
- **Asia:** Korean, the Philippines, Japan, China
- **Northern Europe:** Sweden, Finland, Demark, Russia
- **Southern Europe:** Portugal, Spain, Italy, Greece, Yugoslavia
- **Central Europe:** Germany, Switzerland, Hungary, Austria
- **Western Europe:** Ireland, England, France, Scotland
- **Non-U.S. Americas:** Mexico, "Central America" (listed as the birthplace for UISC-877)

Figure 3.4. *Regional groupings (Birth Location Scheme 2) of European countries of origin for individuals in the UISC.*



1 = Northern Europe, 2 = Southern Europe, 3 = Central Europe, 4 = Western Europe. No individuals in the UISC seem to have emigrated from Eastern Europe.

** Prior to declarations of independence and the breakup of the former Yugoslav Republic in 1980, the "Yugoslavia" referred to in UISC documentation would have referred to the region comprised of Bosnia, Croatia, Slovenia, Macedonia, and Montenegro.*

Table 3.4. *Birth Location Scheme 2 in the UISC and subsample broken down by global region.*

	Documented-UISC Overall			**Subsample (w/femur) Studied**		
	N	Percent	Valid %	N	Percent	Valid %
West U.S.	22	9.6	10.2	16	8.6	9.1
Midwest U.S.	48	20.9	22.2	41	22.0	23.4
South U.S.	14	6.1	6.5	10	5.4	5.7
Northeast U.S.	25	10.9	11.6	23	12.4	13.1
Asia	19	8.3	8.8	17	9.1	9.7
N. Europe	13	5.7	6.0	9	4.8	5.1
S. Europe	16	7.0	7.4	12	6.5	6.9
C. Europe	18	7.8	8.3	14	7.5	8.0
W. Europe	31	13.5	14.4	25	13.4	14.3
Non-U.S. Americas	10	4.3	4.6	8	4.3	4.6
Missing	14	6.1		11	5.9	

From the analysis, it is clear that the bulk of foreign-born persons in the UISC originated from Western Europe. Only more people migrated from the Midwest to the Bay Area than from Western Europe. Despite the close proximity of Canada to Northern California, it is not represented as a country of origin within the UISC. Similarly, Mexico also borders California to the south and yet a relatively low proportion of individuals living there migrating to the Santa Clara Valley and surrounding regions. The reason for this (perhaps surprising) trend likely centers around labor. After 1850, the loss of slavery as a legally endorsed means of labor initiated an economic and productivity strain that would be exacerbated by the demands of the Civil War. Wartime depleted cities of abled bodied men and the United States looked to foreigners to close the gap, passing the Immigration Act of 1864 which made it easier for immigrants to form labor contracts and enter the country. Thus, California, as did many states, looked abroad for hardy individuals who would accept the lowest wages. For a time, this appeared to be Chinese individuals, but the Chinese Exclusion Act of 1882 effectively stemmed that stream of labor as well. Consequently, Europe became a deep source of indentured servants who would provide the U.S. government a labor contract for permission to immigrate, and in return would work for an agreed upon number of years for extremely low return. Western Europe seemed the source with the greatest chance of providing workers who at the very least spoke some English. Moreover, their culture was most similar to those already living in the United States, so assimilation could have been perceived as an easier ordeal than for someone from Russia or Korea, for example.

Table 3.5. *Length of residence in the United States and California in years for foreign-born individuals in the UISC overall and the subsample studied.*

		N	Minimum	Maximum	Mean	Std. Deviation
Documented-UISC Overall	**Length of residence in U.S.**	58	4	78	44.12	18.09
	Length of Residence in CA	51	0.67	76	33.60	21.44
Subsample (w/femur) Studied	**Length of residence in U.S.**	49	14	78	46.67	17.05
	Length of Residence in CA	55	0.67	78	35.32	16.98

Note: *There was no statistical difference ($p>.05$) in length of residence (U.S. & CA) between the overall documented-UISC sample and the subsample studied.*

Table 3.6. *Length of residence in California for American-born individuals in the documented-UISC overall and the subsample studied (p>.05).*

	N	Minimum	Maximum	Mean	Std. Deviation
Documented-UISC Overall	62	2	80	38.97	20.07
Subsample (w/femur) Studied	61	1	80	37.54	22.15

Note: *There was no statistical difference (p>.05) in length of residence in California between the overall UISC sample and the subsample studied.*

The stepwise migration of immigrants is evident by comparing the time elapsed between arrival in the United States and length of residence in California (Table 3.5). The difference in length of residence in the United States and length of residence in California is approximately ten years on average for foreign-born individuals. American-born individuals were not examined with respect to "length of residence in the United States" because this would span their entire lifetime and inflate the results. This near-decade long differential would allow immigrants time to become accustomed to American culture and ways of life before migrating to California. The average length of residence in California exceeded thirty years for both foreign- and American-born individuals (Table 3.6), indicating either an inability to move elsewhere or a general complacency towards, if not enjoyment of, the area. Perhaps California was seen as a terminal destination, as it was the final frontier of American settler colonialism's westward expansion. In any case, the individuals who comprise the UISC tended to have lived a significant time both in California and the United States and were likely well-acculturated and socialized into American socioeconomic hierarchies.

Of Birth and Death

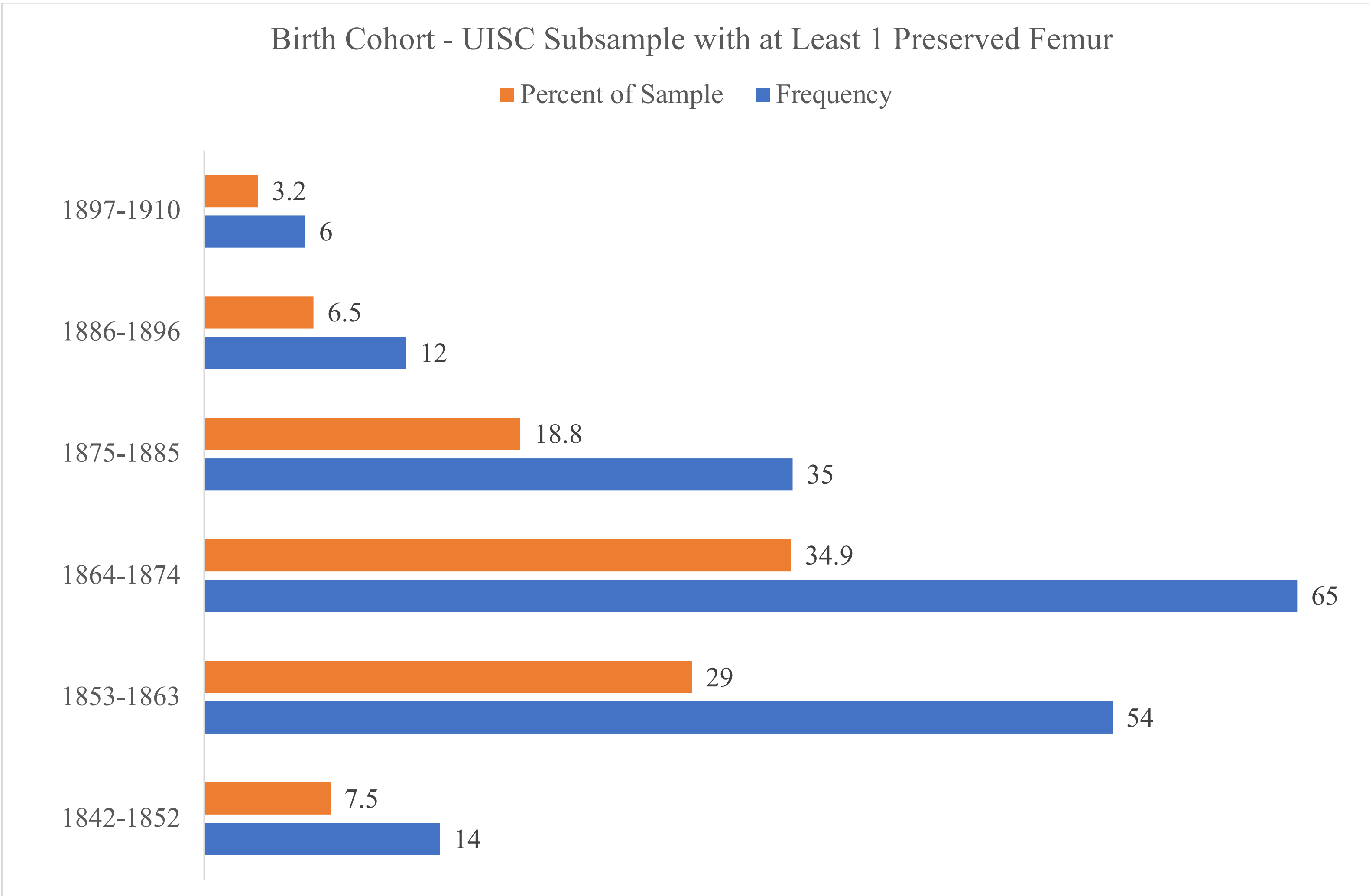
To analyze the spread or concentration of birth years, I first identified the earliest (1842) and latest birth years (1910) for individuals with a preserved femur. I then arranged the year range into a series of birth cohorts, each spanning 10 years with the exception of the latest cohort. Because very few individuals were born in this later period, the final birth cohort spans 13 years to include enough individuals to create a meaningful group (Table 3.7). Performing analysis using birth cohorts rather than individual birth years also helps correct for uncertainty in birth years. For a number of individuals, immigration documents, death certificate documents, and sometimes even marriage licenses show a discrepancy in the listed birth year. In a majority of the cases, this is only a one-to-two-year error range, but the use of birth cohorts lessens the impact of this uncertainty.

In this subsample, the birth cohort containing the largest number of individuals is that which spans the years 1864 to 1874 (Figure 3.5). Overall, individuals born between the years 1853 and 1874 represent nearly two-thirds (63.9%) of the sample. The mean life span of these individuals was a lengthy 69.04 years (std. dev.=13.021) with a minimum age at death of 28 and a maximum of 96 years. Once again, these statistics demonstrate that the subsample studied in this research project is quite similar to the documented-UISC sample overall, in which the mean lifespan was 68.96 years (std. dev.=13.15), and the number of individuals born in each birth year cohort demonstrates near-identical proportions to the group with preserved femora.

Table 3.7. *Number of individuals born in each of the six birth cohorts that span the range of birth years for this UISC sample.*

	Documented-UISC Overall			**Subsample (w/femur) Studied**		
Birth Cohort	N	Percent	Valid %	N	Percent	Valid %
1842-1852	18	7.8	7.9	14	7.5	7.5
1853-1863	65	28.3	28.4	54	29.0	29.0
1864-1874	83	36.1	36.2	65	34.9	34.9
1875-1885	41	17.8	17.9	35	18.8	18.8
1886-1896	14	6.1	6.1	12	6.5	6.5
1897-1910	8	3.5	3.5	6	3.2	3.2
Missing	1	0.4		0	0	0
Total	230	100.00	100.00	186	100.00	100.00

Figure 3.5. *Bar chart comparing birth cohorts by number of individuals (frequency) and corresponding percent of the subsample that count represents.*



In comparison to the variable “birth year,” “death year” ranges for the subsample of interest were not quite as dispersed (Table 3.8). 131 of the total 186 individuals studied (70.4%) died between the years 1929 and 1939. Only 29.6% (n=55) passed away at a later date, with the latest recorded death in 1952. As with all other demographic information presented thus far, there is only a very minor difference between the proportion of individuals in either death cohort when comparing the overall documented portion of the UISC with the subsample of interest, and this difference is not statistically significant.

Table 3.8. *Comparison of year of death between the UISC overall and the subsample with at least one preserved femur.*

	DOCUMENTED-UISC OVERALL		**SUBSAMPLE (W/FEMUR) STUDIED**	
DEATH COHORT	N	Percent	N	Percent
1929-1939	163	70.9	131	70.4
1940-1952	67	29.1	55	29.6

All but two individuals in the documented-UISC are associated with a known cause of death (COD). However, these causes of death are varied and quite specific, including anything from chronic nephritis to hyperstatic pneumonia. To create meaningful generalized categories from this eclectic list of medical conditions, I referenced the World Health Organization’s (WHO) International Classification of Diseases (ICD). The ICD takes an incredible array of human conditions and indexes them into 4 extremely broad categories: communicable conditions, non-communicable diseases, injuries, and ill-defined diseases. For the causes of death found in the UISC, no ill-defined diseases were recorded and only one individual’s COD was attributed to an injury, specifically suicide by jumping in front of a car on the highway. Most individuals in the UISC perished from non-communicable disease, of which cardiovascular disease was clearly the leading COD (Table 3.9). According to the WHO, cardiovascular disease refers to any disorder that affects the heart of blood vessels and can include deep vein thrombosis (blood clots), rheumatic heart disease, cerebrovascular disease, hypertension and inflammatory heart diseases. The second leading cause of death amongst UISC individuals due to a noncommunicable disease is malignant neoplasm, also known as a cancerous tumor. Given the relatively long lifespan of individuals in this collection, it is not surprising that several of them perished due to an array of cancers.

The remaining noncommunicable diseases CODs apply to only a small proportion of the UISC. Respiratory diseases, such as asthma and chronic obstructive pulmonary disease, account for only three deaths in the larger UISC sample, while genitourinary disease (e.g., nephritis) accounts for five. Digestive disease, like appendicitis and cirrhosis of the liver, account for perhaps a surprisingly small number of deaths (COD for 9 individuals in the documented-UISC overall) given that in this period of history, malnutrition and level of alcohol consumption tended to be quite high. The prevalence of diabetes mellitus, injury, and musculoskeletal disease (the only recorded case falling into this category is listed as osteoarthritis with secondary joint disease) are almost entirely negligible. The final type of noncommunicable disease represented in this collection is "neuropsychiatric conditions." Placing diseases into this category requires an understanding of now-antiquated diagnoses. For instance, a number of individuals are listed with a COD of "general paralysis of the insane." While one might feel inclined to categorize this COD as a neuropsychiatric condition due to its use of the word "insane," this diagnosis was commonly employed as a description of the effects of tertiary syphilis, meaning it should be more appropriately categorized as indicative of a communicable disease. Additionally, deaths listed as due to "dementia praecox" would today be attributed to schizophrenia, as more modern research has shown that while schizophrenia may be related to dementia, it is not a *form* of dementia.

Table 3.9. *Causes of death for the documented-UISC overall and the subsample of interest.*

	Documented-UISC Overall			**Subsample (w/femur) Studied**		
	N	Percent	Valid %	N	Percent	Valid %
Cardiovascular Disease	142	61.7	62.0	115	61.8	62.2
Malignant Neoplasms	14	6.1	6.1	14	7.5	7.6
Infectious and Parasitic Disease*	31	13.5	13.5	22	11.8	11.9
Respiratory* Infection	17	7.4	7.4	15	8.1	8.1
Respiratory Disease	3	1.3	1.3	3	1.6	1.6
Digestive Diseases	7	3.0	3.1	5	2.7	2.7
Neuropsychiatric conditions	7	3.0	3.1	5	2.7	2.7
Genitourinary Disease	5	2.2	2.2	5	2.7	2.7
Diabetes Mellitus	1	0.4	0.4	1	0.5	0.5
Musculoskeletal Disease	1	0.4	0.4	0	0	0
Injury	1	0.4	0.4	0	0	0
Total	229	99.6	100.00	185	99.5	100.00
Missing	1	0.4		1	0.5	
Total	230	100.00		186	100.00	

**These categories are the only two which represent communicable diseases. All other COD categories are noncommunicable conditions.*

Some form of communicable disease does account for a notable portion of CODs in the UISC at an incidence rate of about 21%. Given the high population density and poor hygiene practices in mining camps and inner-city centers, coupled with the dubious building practices and dumping of waste during industrialization, it is not unexpected that infectious disease ended the lives of many in the Bay Area. Tuberculosis is by far the most listed communicable COD, which would have been easily spread through coughing and sneezing in camps and other congested areas. Syphilis is another fatally infectious disease of note. The only other category of communicable disease that is applicable to this population sample is that of respiratory infections. This category is almost exclusively comprised of a singular COD: bronchopneumonia. Bronchopneumonia is a condition caused by a bacterial infection triggering inflammation that prevents adequate air supply to the lungs and is particularly likely to be fatal in immunocompromised individuals, such as the elderly, the malnourished, or those already sick. Overall, the COD breakdown between the documented-UISC and the sample studied for this research project are highly similar to one another as well as to modern data. According to the Health Disparities Dashboard, chronic diseases like cardiovascular disease and cancers (malignant neoplasms) are still the leading causes of death in the San Francisco area today. However, death due to infectious (communicable) disease is greatly lessened in the modern era, likely due to the development of vaccines and general improvement of treatment options.

To Live is to Labor

Documentation for occupation may come from a variety of sources. Occasionally, it is associated with death certificates. Other times it may be listed on asylum or hospital intake forms. Most reliably, it is listed on census forms once a decade. Transforming a plethora of listed occupations into quantifiable data relies on a series of choices. The variety of documented jobs vary from as specific as cabinet maker to as broad as "laborer." Thus, it is clear that from this pool of jobs, I must create some meaningful categorizations. To do this, I referenced the Bureau of Labor Statistics' (BLS) list of occupational profiles which places almost all known jobs into a series of broad categories. Although the BLS utilizes 22 different occupational groupings, only 13 are represented by the individuals in the UISC (numbers 2-14 in Table 3.10). While the jobs under some headings might be self-evident, such as lawyers being classified under "legal occupations," others are less clear. For instance, bakers fall under the category of "production occupations," while servers and bussers fall within "food preparation and serving related occupations." "Construction and extraction occupations" encompass carpenters, stonemasons, electricians, etc. "Transportation and material moving occupations" can refer to flight attendants, any type of driver, captains and sailors. Many women were designated with the occupation of "housewife." For these individuals, I placed them within the category of "Building and grounds cleaning and maintenance occupations" because this type of labor seemed to match others in this grouping such as janitors, maids, housecleaners, and groundskeepers, the main distinction being that housewives did not receive a salary for their labor.

To the BLS categories used, I also added the classifications of "laborer" and "inmate." The category of laborer was a popular designation on census records that could refer to a variety of jobs. For every individual, I used ancestry and genealogy websites to narrow down what "laborer" might mean for specific individuals. For some, I was able to find historical documents that clarified the type of work, but for 52 individuals, I was not able to find more detailed information. Consequently, instead of omitting these individuals from further analysis, I have decided to retain the category of "laborer" in an attempt to see if it has any meaningful relationship to intercondylar notch development and morphology. I have also added the category of "inmate," but this term does not describe people in the carceral system like it does today. Rather, it was used as a designator for residents in senior care facilities or asylums who did not have jobs. Many individuals in the UISC were listed as inmates on multiple census surveys, meaning they were out of paying work for a notable period. Though they were not being paid for labor, individuals referred to as "inmates" were continuing to have relationships, go for walks, read, play games and otherwise engage in day-to-day routines. Therefore, the category of "inmate" can still represent, to a degree, the type of behavior and activity level of an individual.

Another question one must ask when treating occupation/labor as a meaningful variable is: how does this type of categorization work when we understand that most individuals do not work the same job their entire lives? The answer is not a one-size-fits all solution. Individuals must be examined on a case-by-case basis. For instance, in the UISC many individuals did have different job titles throughout their lives, but most of the time these were still in the same relative field. In other instances, individuals did change fields entirely. In this case, I would use census and any other available historical records to determine which in which position they spent the greatest number of years and assign the corresponding BLS label. In any case when an occupation beyond "inmate" or "laborer" could be found, I would forgo the former in favor of the more descriptive category. In situations where an individual was found to have spent relatively the same amount of time in two different fields, I would record only the most demanding position, as this is the one most likely to have affected the body. It is important to note there are still limitations to tracking occupations throughout an individual's life. Most often, we can see a snapshot of someone's life every ten years, but it is much harder to glean insight into the interim years. Based on available information, Tables 3.10 and 3.11 represent the best generalization of the type of work being done by the individuals in the UISC during their lifetimes.

Table 3.10. *Categorization of occupations for UISC individuals using the Bureau of Labor Statistics' official occupational profile groups.*

	Documented-UISC Overall			**Subsample (w/femur) Studied**		
	N	**%**	**Valid %**	**N**	**%**	**Valid %**
1. Inmate (in home) *	22	9.6	11.0	15	8.1	9.2
2. Building and grounds cleaning and maintenance operations	28	12.2	14.0	21	11.3	12.9
3. Food preparation and serving related occupations	15	6.5	7.5	13	7.0	8.0
4. Sales and related occupations	7	3.0	3.5	6	3.2	3.7
5. Construction and extraction occupations	18	7.8	9.0	16	8.6	9.8
6. Farming, fishing, and forestry occupations	20	8.7	10.0	19	10.2	11.7
7. Legal occupations	1	0.4	0.5	1	0.5	0.6
8. Life, physical, and social science occupations	2	0.9	1.0	1	0.5	0.6
9. Architecture and engineering occupations	3	1.3	1.5	3	1.6	1.8
10. Production occupations	11	4.8	5.5	9	4.8	5.5
11. Office and administrative support occupations	8	3.5	4.0	5	2.7	3.1
12. Personal care and service occupations	4	1.7	2.0	4	2.2	2.5
13. Healthcare practitioners and technical occupations	2	0.9	1.0	2	1.1	1.2
14. Transportation and material moving occupations	7	3.0	3.5	4	2.2	2.5
15. "Laborer"	52	22.6	26.0	44	23.7	27.0
16. Missing	30	13.0		23	12.4	

***For Table 3.10:** *Inmate refers to a resident of a senior home, almshouse, or asylum who no longer holds a wage-paying job, but who also was not properly "retired" in the sense that they were no longer independent.*

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Table 3.11. *BLS occupational categories aggregated into groups and arranged by physical intensity level from least to most demanding.*

	Documented-UISC Overall			**Subsample (w/femur) Studied**		
	N	**%**	**Valid %**	**N**	**%**	**Valid %**
Inmate (in home)	22	9.6	11.0	15	8.1	9.2
Legal occupations**;** life, physical, and social science occupations; office and administrative support occupations	11	4.8	5.5	7	3.8	4.3
Sales and related occupations; architecture and engineering occupations; personal care and service occupations; healthcare practitioners and technical occupations	16	7.0	8.0	15	8.1	9.2
Food preparation and serving related occupations; production occupations; transportation and material moving occupations	33	14.3	16.5	26	14.0	16.0
Building and grounds cleaning and maintenance operations; construction and extraction occupations; farming, fishing, and forestry occupations	66	28.7	33.0	56	30.1	34.4
"laborer"	52	22.6	26.0	44	23.7	27.0
Missing	30	13.0		23	12.4	

Although use of the BLS scheme does most efficiently summarize the diverse array of occupations represented within the UISC, the spread of 163 individuals in the subsample (omitting those missing documented jobs) over 15 categories makes them so sparsely populated as to have barely any meaning at all. Consequently, I sought a way to combine occupation type with labor level. In Table 3.11, I have aggregated the BLS categories into groupings that I believe represent relative physical labor demand. While these grouping are, of course, subjective to a degree, in a way they also are not, as it is likely universally agreed upon that the physical demands of legal occupations are lower than for those in farming, fishing, and forestry occupations. In Table 3.11, these aggregate groups are arranged from least to most physically demanding

Those with the designation of "inmate" represent the least labor-intensive group, as they were not being paid for labor and therefore had no quotas or specific contracts to meet. While they were still interacting with others and likely somewhat active, most of the time was not regimented in a way that wage-working jobs were. The second lowest labor-intensive category encompasses: legal occupations; life, physical, and social science occupations; and office and administrative support occupations. These types of jobs largely required stationary work, laboratory work, and academic professions that allowed ample seating time, little heavy lifting, and short distances walked. In the third category (mid-level physical intensity), I group together: sales and related occupations; architecture and engineering occupations; personal care and service occupations; and healthcare practitioners and technical occupations. For the mid-upper physical intensity grouping, I include: food preparation and serving related occupations; production occupations; transportation and material moving occupations. Most of these occupations would necessitate long days of moderate lifting and the production of things by hand. Finally, on the high end of physical intensity cluster: building and grounds cleaning and maintenance operations; construction and extraction occupations; and farming, fishing, and forestry occupations. These jobs required the longest hours, the lowest pay, and some of the most dangerous occupational contexts. Because the category including maintenance operations includes housewives, some may argue that it does not belong in this aggregate grouping. In response, I argue that unlike all other occupations listed by the BLS, this is the only one that does not have set designated hours. There was no punch card to clock in or out on being a housewife, and the chores could be grueling, including lifting and carrying small children and loads of laundry. The category of "laborer," as aforementioned is a bit of a miscellaneous grouping, but likely represented the people carrying out the odd jobs that no one else wanted to do, perhaps because of the challenging nature, such as sewage maintenance or dockworkers. It is probable that these individuals were among the most exploited.

The Potential Impact of Unionization

The first workers' union in the United States was formed in 1794 by shoemakers and other craftsmen in Philadelphia ahead of wage negotiations with management (Greenberg, 2014). This would initiate the beginning of a turbulent union history plagued with arrests, conspiracy trials, and strikes. The uphill battle fought by wage workers for union protections explains why the first country-wide membership, the National Labor Union, was not founded until nearly a century later in 1866. It was at this point that union formation would begin to gain steam, but the power held by these membership groups could not really be considered "strong" until the Great Depression (Dray, 2010). The timeline of this movement occurs a bit late for it to have had much of an effect on the individuals studied in this research project. Moreover, none of the primary documentation (e.g., newspapers) or historical literature on the Santa Clara Valley examined within the scope of the literature review for this dissertation indicate any notable unionization in the area. There is ample evidence of what Kazin (1989) calls a "labor barony," or a strong and widespread union presence in San Francisco proper from the late 1890s which would grow to reach the surrounding regions, but again, the timing of this process excludes the bulk of the lived experiences of many in the UISC. Thus, overall, the potential impact of unions and the unionization process on these particular individuals is likely negligible.

3.5 CONCLUSION

There is undoubtedly a bias in the study sample. It is quite clear from the demographic information that this collection is heavily weighted towards older, white males. It is not my intention to continue the trend of telling history through the lens of the dominant group. I do not intend to marginalize the stories or experiences of those that are continually left in the background. The makeup of the subsample does not reflect differential preservation of femora in certain groups, but rather is representative of the makeup of the UISC overall. However, given the diversity of San Francisco and Santa Clara Valley, coupled with the understanding that "donated" bodies in this period were often those with no family or means to pay for burial rites, does make it worth examining why more persons of color are not present in the collection. Based on the history of the almshouses, asylums, and hospitals from which these bodies were sourced, it is clear that the primary patients/residents were white males. The explanation for this pattern is likely complex. There do not appear to be any apparent rules ostracizing or otherwise barring women from these spheres. However, while nations of origin represented in the greater Bay Area were highly diverse during this period, the sex ratio was excessively skewed. Recall that California's population during the gold rush period was well over two-thirds male. Thus, the population makeup in almshouses, asylums, and hospitals was purely a reflection of trends of the broader populace.

There may be other potential contributing factors. Women were perpetually assumed to be in a state of dependence. Therefore, it is likely that women had a larger informal safety net that allowed for acceptance of living with friends/relatives rather than having to resort to almshouses and long-term care facilities. For men, on the other hand, this would have been stigmatized and they may have believed that they could retain a greater façade of independence within these institutions than through being taken in by others. In contrast, people of color may have fostered a distrust of institutions such as these given the country's tendency to enslave, disenfranchise, and otherwise exploit non-white bodies and opted to refrain from accessing these resources. Of course, it is also possible that they were informally denied entry due to stereotypes about who the "deserving poor" were and what they looked like.

The UISC was chosen as the collection of focus because it has a wealth of associated documentation and relatively little written or published about it. In other words, the primary driving reason behind the choice in research material was the ability to historically contextualize results while giving back to the holding institution, not the demographics of the collection itself. Given the bias in who is represented in this collection, it is fair to question whether the results of this research will be telling the whole story. The answer is, of course, to the contrary. This documented collection is comprised of 230 individuals – regardless of what races, nationalities, and sexes they represented, it would still be impossible to claim that an entire picture could be painted.

What I can do, though, is offer a starting point, a reference group for further research to add to and expand upon. This sample presents an opportunity to examine a localized construction of whiteness and how it is unique from other versions. Because “whiteness” is not a category developed in isolation, but rather in relation to something else, we still have an opportunity to learn about the oppositional “non-whiteness.” In understanding who could access the label of “white” and what acceptable “white labor” looks like, we can also get a sense of what the opposite looked like. Through reflexivity that understands the limitation of this research, and the necessity to prevent enacting further harm on these already marginalized individuals, I hope to present an ethical, considerate project that can reveal insights about the relationship between the development of the intercondylar notch, and the historical context in which these individuals lived.

Chapter 4: Osteological and Statistical Methods

4.1 INTRODUCTION

For the purposes of this research, I will only consider osteologically mature individuals, defined as those exhibiting fusion at the distal femoral epiphysis. Complete fusion of the distal femur typically occurs by 16 years of age, but the youngest individual in the documented-UISC subsample was 27, so stage of fusion was not a concern. Younger individuals would have been excluded from this research as it is primarily concerned with an average, accumulated life experience. Prior to fusion of the femoral epiphyseal plate, the capacity for developmental elasticity is much greater and more sensitive to brief disruptions in mobility patterns (Gosman et al., 2013; Lieberman et al., 2001; Ruff, 2005). In other words, the high skeletal elasticity in subadults means that bone morphology is in constant flux. As a reminder, elasticity refers to short-term, micro-fluctuations in bone, while plasticity refers to long-term, often macroscopic changes in bone morphology. Epiphyseal fusion indicates a "setting" of the bone and a limitation to remodeling. Therefore, skeletally mature bone indicates average mechanical forces over time, rather than the "snapshot" given by juvenile bone.

4.2 AGE AND SEX

The holding institutions have previously estimated sex and age of all individuals in the sample, but I confirmed these based on standard osteological methods (Bass, 1987; Buikstra and Ubelaker, 1994; Steele and Bramblett, 1988; White et al., 2011). During age and sex estimation processes, the only identifier used was the UISC catalog number to render unknown the previously established sex and age, and limit confirmation bias. I evaluated skeletal sex characteristics, such as pelvic and cranial morphology, and scored these along the standard spectrum of female, probable female, indeterminate, probable male, and male (Bass, 1987; White and Folkens, 2005). Although standard bioarchaeological sex estimation practices often problematically assume that sex corresponds to gender, I will utilize written records to garner additional insight into gender performance. Sex assessments are crucial to revealing labor differentiation within populations and exploring potential inherent skeletal differences in the distal femur. When estimating age-at-death, I utilized a multifactorial methodology that generates separate age ranges from epiphyseal fusion (including the medial clavicle, which is particularly helpful for young adults), cranial suture fusion (Mann et al., 1991; Meindl and Lovejoy, 1985), and age-related changes at the pubic symphysis (Brooks and Suchey, 1990) and auricular surface (Lovejoy et al., 1985). Age will need to be controlled for in subsequent statistical analyses to prepare for the possibility that stenotic notches are related to years of cumulative mechanical stress and/or the natural aging process.

4.3 INTERCONDYLAR NOTCH QUANTIFICATION AND CHARACTERIZATION

Linear Measurements of the Distal Femur

For each individual, I used sliding calipers to gather bilateral measurements for intercondylar notch width and bicondylar width. Bicondylar width is defined as the maximum distance between the lateral and medial condyles of the femur taken at the level of the popliteal groove (Fig. 4.1). Notch width is the maximum horizontal dimension of the inner notch space, also measured at the level of the popliteal groove.

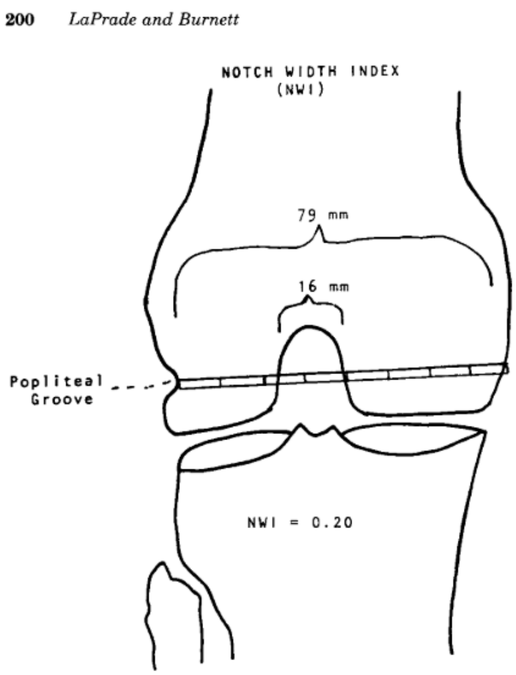


Figure 4.1. *Notch width index (NWI) is calculated by dividing the notch width by the bicondylar width, as measured at the level of the popliteal groove (LaPrade and Burnett, 1994).*

These landmark distances are multipurpose – they will be used to ensure that the rendered 3D model (described below) is to-scale and to assess potential directional asymmetry in the knee. Notch width index (NWI) is calculated by dividing notch width by bicondylar width (LaPrade and Burnett, 1994). The literature (e.g. Shelbourne et al., 1998) indicates that the intercondylar notch does not grow allometrically; femoral bicondylar width increases with height, notch width does not. The implication is that absolute notch width would be a more accurate quantification of the notch than NWI. Despite this, I have chosen to use NWI as the basis by which to categorize notches as stenotic/non-stenotic because the definition of stenotic, as used widely in clinical literature, is defined based on NWI cutoffs. To pursue research that is comparable to other studies, I must use the standard definition.

Following clinical literature, I categorized intercondylar notches as stenotic based on NWI. There is some minor variation in the literature (Bouras et al. 2018; Sanchis-Alfonso and Tinto-Pedrerol, 2000; Souryal and Freeman, 1993), but most studies define stenotic notches as having any index less than or equal to 0.20-0.25 (Anderson et al., 1987; Hoteya et al., 2011; LaPrade and Burnett, 1994; Lombardo et al., 2005; Muneta et al., 1997; Souryal et al., 1988; Stein et al., 2010). To be as inclusive as possible, I chose to make the cutoff the greatest aspect of this range. Therefore, the two osteological groups I will be considering are stenotic (NWI≤0.25) and non-stenotic (NWI>0.25).

Intraobserver error margins for measurements relating the distal femur were calculated, as these measurements are the most crucial to this dissertation and may be less familiar to others than whole bone measurements. For the linear measurements – bicondylar breadth and notch width – error is best presented in terms of standard deviation (SD), technical error of measurement (TEM), relative TEM (rTEM), and coefficient of variation (CV). TEM is a very commonly used measure of precision and is calculated as the square root of measurement variance (Arroyo et al., 2010). rTEM takes the absolute TEM and transforms it into a percentage relative to the variable mean. Finally, CV is the ratio of the standard deviation to the variable mean. A CV of lower than 1 seems to be the cross-discipline standard of "good" repeatability and indicates low variance in intraobserver measurements. These representations of intraobserver error are presented below in Table 4.1. Results indicate that intraobserver variance of measurements are well below 1mm, whether gauged by SD or TEM. rTEM shows that these variances are below .5% of the variable average, which demonstrates a high level of repeatability. CV values are also well below the "good" threshold of 1. Taken together, these different gauges of intraobserver error indicate that high variance in measurement is not a concern.

Table 4.1. *Statistical gauges of intraobserver error for linear measurements quantifying morphology of the distal femur.*

	Standard Deviation	**TEM**	**rTEM**	**CV**
Bicondylar Breadth	.08mm	.01mm	.01%	.00
Notch Width	.24mm	.10mm	.42%	.01

*All measurements were repeated 10 times and measured in millimeters (mm).

Race and Stature

Maximum femoral length was recorded in millimeters, converted to centimeters, and used to estimate stature based on regression formulae calculated by Bass (1987). Maximum femoral length was used preferentially, but when not available, maximum tibial length was substituted. In one case, neither of these measurements were recordable, so fibular length was utilized. Regression formulae used to calculate stature are listed in Table 4.2. Because this population sample is primarily older individuals, it is necessary to control for stature loss due to the aging process, during which cartilage compresses. Most individuals over the age of 30 have experienced some of this stature loss due to the aging process. All but one individual in the UISC subsample studied are over the age of 30 and thus are subject to some degree of stature loss. This was calculated following Trotter and Gleser's (1958) revised equation: potential height (cm) – [0.06*(age-30)]. It is important to control for body size when looking for notch differences independent of overall body size variation.

It is worth addressing why the racial categories present in Table 4.2 are used to apply stature formulae, since I reject them throughout this dissertation. First, height is a characteristic with high heritability (e.g., Jarvis et al., 2012; Stulp and Barrett, 2016). Second, from an evolutionary perspective, the local environment places a selective pressure on stature. Stockier bodies, like those of the Neanderthals, help retain body heat in cold environments, while taller, lankier bodies allow for more efficient cooling in hotter climates (Churchill, 1998; Ruff, 1993). Of course, stressors such as malnutrition can also limit achieved height, but it is generally accepted that the genetic code largely determines stature *potential* (Leroy and Frongillo, 2019; Lifshitz, 2009; McEvoy and Vissher, 2009; Rotwein, 2020). Thus, because height is both heritable and representative of evolutionary history, stature patterns across ancestry groups are evident. Unfortunately, most of the longest used, well-established stature regression equations try to capture this variation through racial groupings. Alternative methods do exist, such as the whole skeleton approach (Raxter et al., 2006; Willey, 2020) which does not require categorization into racial or ancestry groups, but it does necessitate a relatively complete skeleton and would not be useful for this collection. My use of Bass' (1987) regression equations with antiquated groupings reflects: (1) limitations of the UISC sample, (2) lack of available, tested, and replicable methods for partial skeletons, and (3) the need for the sample from which the regression equations were derived to closely approximate the geographic/temporal context of the UISC.

Table 4.2. *Regression equations used to calculate stature for individuals in the UISC (Bass, 1987).*

Bone	Race*	Male Equation	Female Equation
Femur	Caucasoid	2.32 * femur + 65.53 ± 3.94 cm	2.47 * femur + 54.10 ± 3.72 cm
Femur	Negroid	2.10 * femur + 72.22 ± 3.91 cm	2.28 * femur + 59.76 ± 3.41 cm
Femur	Mongoloid	2.15 * femur + 72.57 ± 3.80 cm	Not available (but not needed)
Tibia	Caucasoid	2.42 * tibia + 81.93 ± 4.00 cm	Not needed
Fibula	Caucasoid	2.60 * fibula + 75.50 ± 3.86 cm	Not needed

***Note:** *Racial categories listed in Table 4.2 represent the terminology of the authors, not my own.*

Three-Dimensional Modeling Methods

The characterization of the distal femur using NWI is necessary for comparative purposes with prior medical literature. However, one of the primary driving justifications for the necessity of this type of research project is that this is an oversimplification of a dynamic joint. The knee joint can perform an array of movements – flexion, extension, rotation – which necessitate an equally diverse movement and interaction among the ligaments in this notch space. I argue that the two linear measurements that comprise NWI cannot properly capture the entirety of the notch given that it exists in three dimensions, not two. The neglect to incorporate or acknowledge notch depth or notch height means that only one dimension of the intercondylar fossa is actually being examined, a rather limiting view. In response, this dissertation uses Polycam technology create three-dimensional, interactive scans of the distal femur via photogrammetry.

Before taking any pictures of the bone, the femur was laid so that the distal half was extended off the end of the laboratory table, dorsal side up, and a small paper scale was laid just above the condyles. The Polycam app was then used on a smartphone to take 200-250 high resolution photographs as the phone was rotated around the entirety of the distal portion of the bone. The app then stitches these photographs together to render a manipulable model (Fig. 4.2). This model was exported from the app into an object file and uploaded into Autodesk Meshmixer software. A software capable of measuring and altering meshes is necessary because photogrammetry can only create a model of the exterior of an object, referred to as a mesh. This mesh is comprised of thousands of vertices which represent areas of higher and lower elevation and help to create a micro-topography of the object being modeled. These vertices are connected by a large web of interconnecting best-fit lines, upon which a geometric mesh is laid. Texture is extracted from the photographs and applied on top of the geometric mesh, recreating the original object digitally.

Figure 4.2. *2D image taken from a rendered 3D scan in Polycam with scale placed above condyles.*

Upon uploading the model to Meshmixer, I first needed to make sure the rendering was to-scale. When using Meshmixer, the imported model generates its own units, but all distances are proportional to those in the real objects. Therefore, I needed to use the program’s digital measuring tool to trace the length of the one-centimeter unit on the scale placed on the bone (this is the importance of including the scale in the initial photographs), and program the software to recognize this as representing 10 millimeters. Thus, all further measurements performed, and volumes calculated, would represent real-world distances in millimeters. Next, the scans needed to be "cleaned." In the process of taking numerous pictures, sometimes background texture or objects are captured that are irrelevant. Using editing tools in Meshmixer, I selected and erased the "noise" in the scan that was unnecessary to the impending analyses. Once the scan only contained the very distal portion of the femur, the mesh was then solidified to fill in any small holes in the exterior as well as the entirety of the interior (Fig. 4.3).

When finding the volume of the space referred to as the intercondylar notch or fossa, as much of the process must be standardized and automated as possible to reduce intra- and inter-observer error. First, I overlaid a solid sphere over the distal femur (Fig. 4.4) that has a diameter equal to the bicondylar width divided in half and with 3mm added (Fig. 4.5). With much testing, this formula was found to create a sphere that could reliably fill the notch space for every femur. The use of a standardized formula for determining what size sphere to import keeps everything proportional to body size and helps standardize the process. If a different sized sphere were to be used each time, it would introduce more variability into the process. Next, using the x-, y-, and z-axes, the sphere was maneuvered to best fill in the notch, attempting to get the sphere to align with the interior notch ridge as closely as possible (Fig. 4.6). This is the point at which human error can primarily be introduced.

Once the sphere was situated adequately, it was converted from a mesh to a solid, and a Boolean difference function was performed. The Boolean difference function removes the areas of overlap between the two models as well as the rest of the femur model. When using the Boolean difference tool, the order in which you select your solids/meshes determines which one remains. In this case, I elected to keep the sphere as the primary object. Thus, once the overlap and the other solid were eliminated, only the digital molding of the notch space remained (Fig. 4.7). Finally, the volume of this remaining solid was calculated by Meshmixer using the "stability" tool and is presented in the units of millimeters cubed (mm^3).

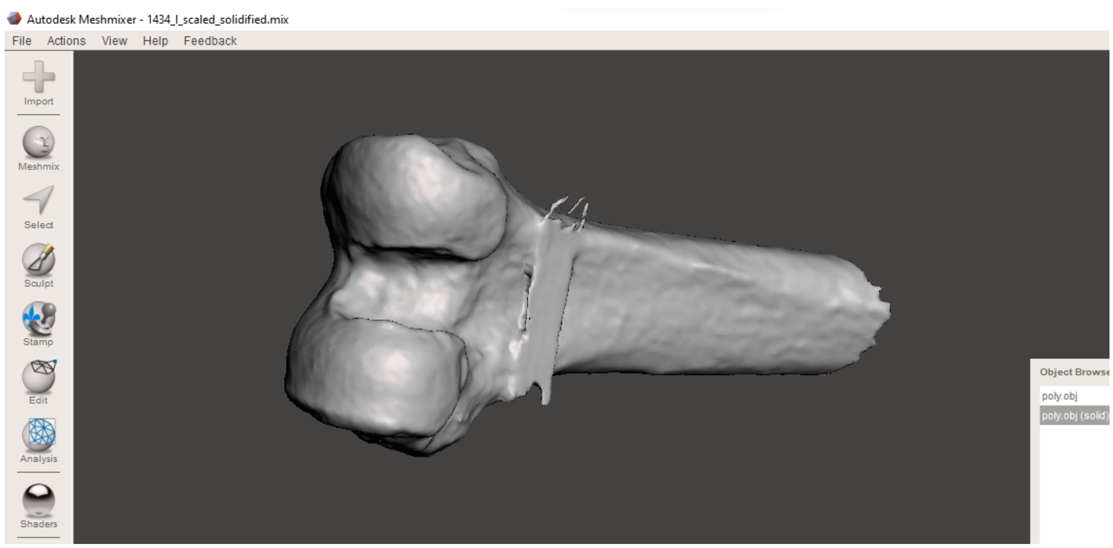


Figure 4.3 (above). *Solidified object after mesh had been cleaned of "noise," or extraneous pieces of 3D scan.*

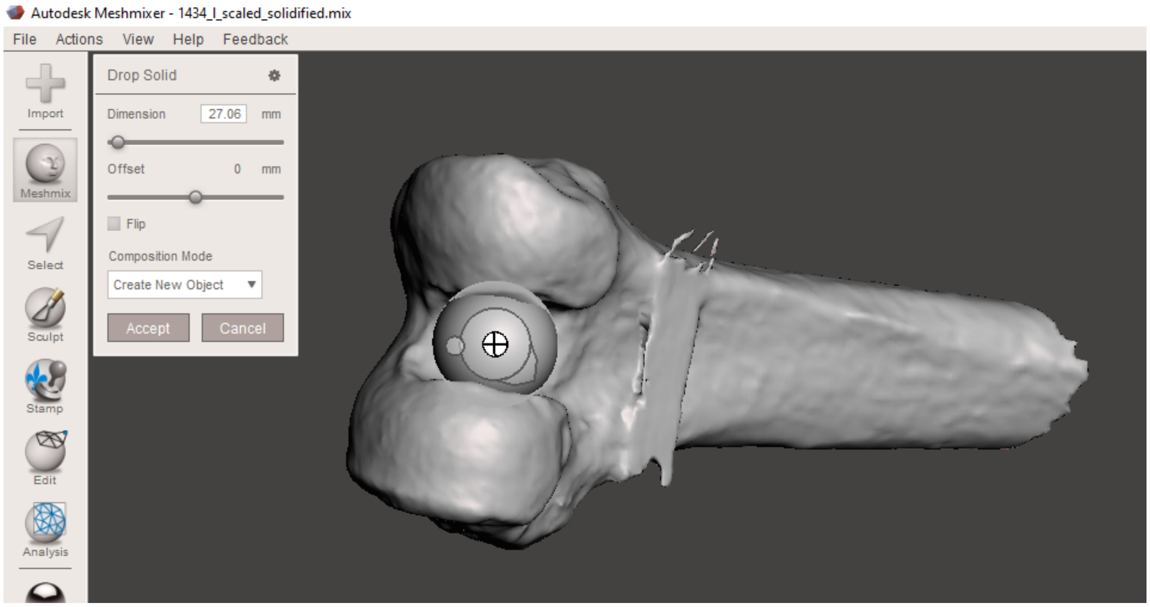


Figure 4.4 (above). *Spherical mesh superimposed over the intercondylar notch.*

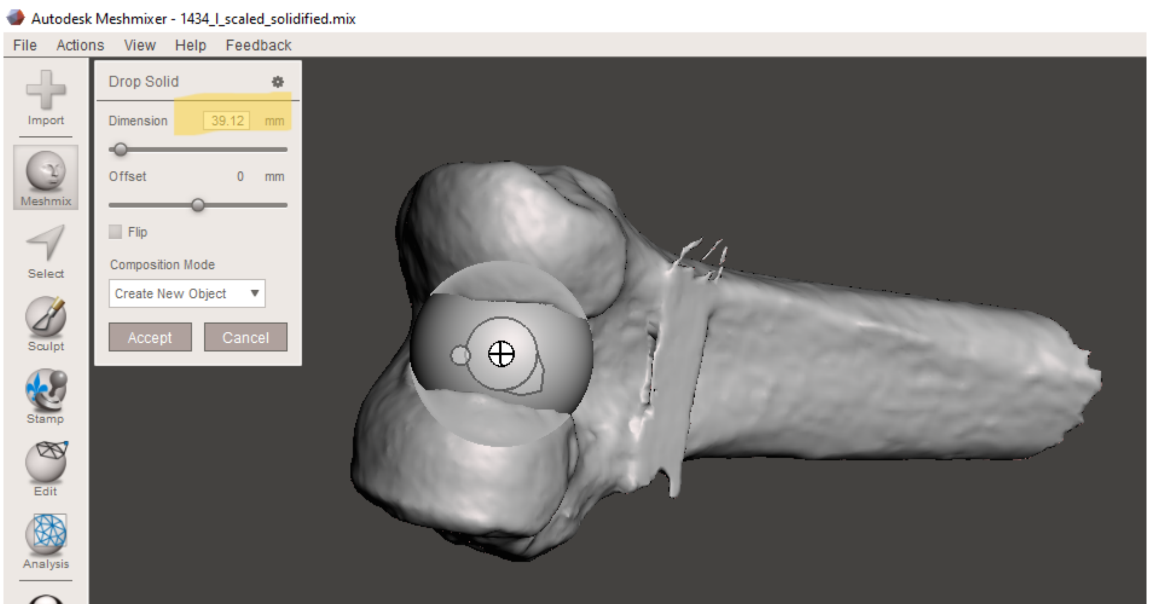


Figure 4.5 (above). *Diameter of the spherical mesh adjusted to:(bicondylar breadth/2) +3mm.*

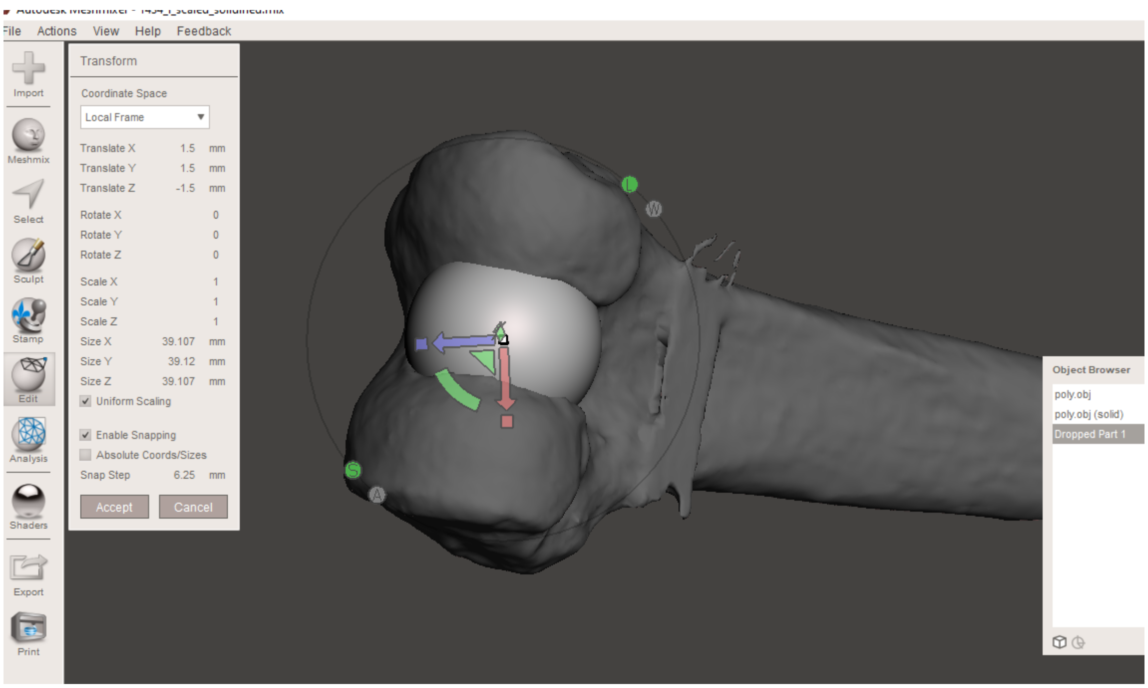
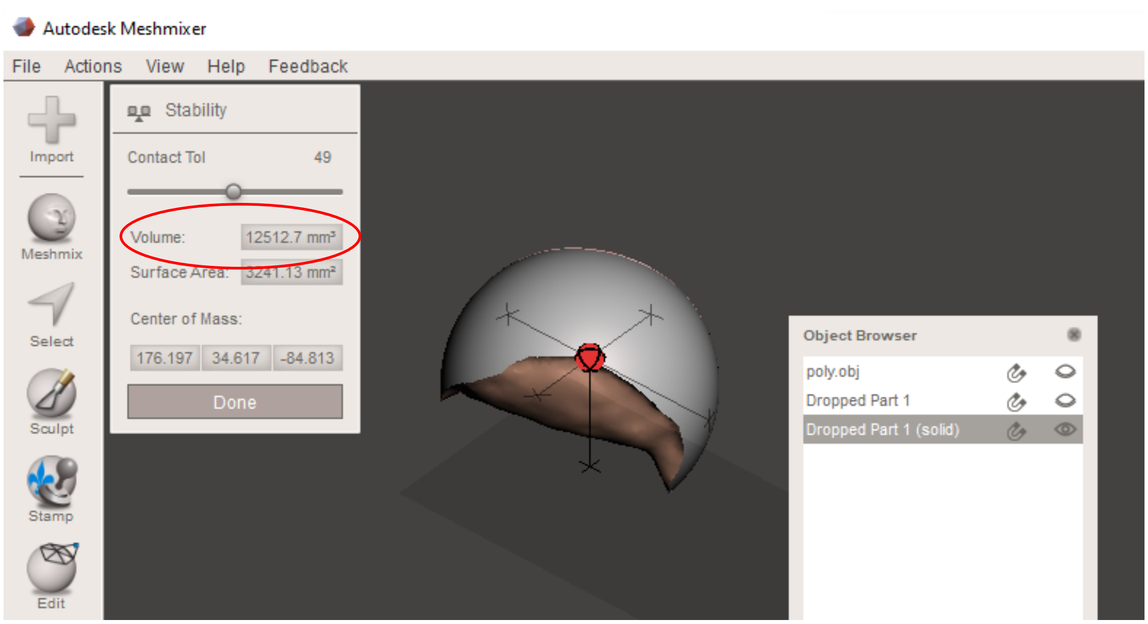


Figure 4.6 (above). *Location of the spherical mesh adjusted in the x-, y-, and z-axis directions until it matches the parameters of the notch space.*

Figure 4.7 (below). *After the spherical mesh is properly located, it is transformed into a solid and a Boolean difference function performed. The object left behind is the 3D representation of the intercondylar notch volume (mm^3).*



When maneuvering the sphere to fit within the intercondylar notch space, the "best fit" will vary from person to person, and even between trials conducted by the same person. To reduce the impact of this error margin, I worked through the aforementioned process three times for each femur and calculated the average of the three resulting volumes. Standard deviation was low at approximately $0.33cm^3$ overall. For reference, 1 cubic centimeter is equivalent to 1 milliliter. So, standard deviation between volume measurements of the same intercondylar notch were around one-third of a milliliter, which is relatively quite small. For a better characterization of how "good" or "bad" this amount of variability is, an ANOVA with repeated measures test was administered via SPSS. Statistical significance here, and throughout the entirety of this dissertation, is set at $\alpha=.05$. This means that all p-values less than .05 will be considered statistically significant. The results of the ANOVA with repeated measures test indicated that measurement of the intercondylar fossa volume does not vary significantly between repeated calculations and is therefore a reliable method with limited intraobserver error ($F=.299$, $p=.742$).

It is important to note that (as far as I am aware) this is the first time that the volume of the intercondylar notch has ever been calculated from dry bone. As a novel approach, there are avenues for further development and expansion. One such possible avenue is looking into the use of rays in Meshmixer. Hypothetically, rays could be "shot" from the vertices on the edges of the intercondylar notch mesh towards each other meeting in the center and creating an array of arcs that span the dorsal aspect of the notch space. These could potentially be used to create a notch face that, rather than the smooth face created by the sphere in the methods listed here, would be more of a topographic match for the irregularities of the notch itself, perhaps characterizing it more accurately. Unfortunately, no one has been able to figure out how to write this process into Meshmixer software as of yet, but it does offer a promising avenue for further development of this method.

4.4 METABOLIC STRESS

Stress refers to a disturbance to homeostatic (i.e., "normal") biological balance that the body attempts to counter through cultural or corporeal means (Goodman et al., 1988; Ham et al., 2021). Often, the biological attempts at correcting these types of disruptions leave evidence within the skeletal system that bioarchaeologists can utilize to understand past variations in human health (Cohen and Armelagos, 1984; Ham et al., 2021). In this dissertation, I refer specifically to metabolic stress to make clear the distinction between burdens on the immune system and divergences from "normal" growth, and bone stress markers related to labor. The pathologies examined in this section (e.g., periosteal reactions, porotic hyperostosis, cribra orbitalia, etc.) reflect upstream causes such as nutrient deficiencies and pathogen load, not degree of labor. The study of osteological stress markers of labor, operating on the understanding that heavily used muscle groups will be more robust with more pronounced attachment sites, is a well-researched subfield of bioarchaeology, but is not within the scope of this particular project. Thus, when the term "stress" is used throughout this work, it refers specifically to metabolic stress.

Osteological patterns in presentations of stress may vary across and within groups and are often interpreted through the lens of structural violence and its explanation of differential burdens of harm and resource access. Examples of factors that might present challenges to the body include living conditions, dietary imbalance or nutrient deficiency, physical trauma, and disease burden (Coelho and McGuire, 1999; Dent, 2017; Savitt, 1978). The body has a finite amount of energy to allocate to its various functions, and stressors cause trade-offs, or a change in allocation of energy from one area, such as growth, to another, like fighting an infection. The reliance on trade-offs does not represent a lack of functioning in the body's immune system; rather, it represents that the body is performing exactly as it should and is strong enough to stem energy use in one area and successfully divert it to another. Trade-offs are one way that the body exhibits adaptive plasticity, or the ability to quickly adjust to new environmental conditions "until selection or biocultural modifications to the environment reduce the likelihood of mortality or extinction" (Temple, 2019: 35).

Bioarchaeological analyses of the bone markers of metabolic stress seek to understand the relationship between traces left on the bone, inequitable patterns in stress within and between groups, and the larger sociocultural and environmental contexts. For this dissertation, I build on this to ask a more specific question – whether there is a relationship between evidence of metabolic stressors and the development of notch narrowing and stenosis. While analysis of metabolic stress markers can reveal useful information about life histories and population-level trends, we must understand that this information is not enough for a complete picture of health (Steckel et al., 2002). Acute conditions typically pass through the body too quickly for bone to develop an identifiable response. Therefore, the measures of health status examined often can only indicate information about chronic conditions. Because acute conditions, especially those that result in mortality, do not register on the bone, frequencies of metabolic stress markers may overrepresent the "healthy" population and underrepresent the "stressed" population. This will be discussed in depth further in a later section in this chapter.

Porotic Hyperostosis and Cribra Orbitalia

Porotic hyperostosis (PH) is one of the most commonly documented pathological conditions in archaeological remains and was previously thought to be strongly associated with iron-deficiency anemia. More recent work, particularly that of Walker and colleagues (2009: 109), has challenged this view and demonstrated that other types of anemias and infections may be more likely culprits. Therefore, PH is currently best interpreted as a non-specific stress indicator. PH, while able to be diagnosed via radiographic images and its classic hair-on-end appearance (Martin and Rackard, 2016), is typically identified macroscopically as areas of porosity on the external table of the parietal bones. The development of porosity is preceded by an expansion of the diploë (spongy portion of the cranial bone) and the bone marrow it contains, which can be caused by increase in cell number (hyperplasia) or cell size (hypertrophy) (Rinaldo et al., 2019: 3549). Both of these mechanisms cause an expansion within the cranial vault, which forces accommodation in the cortical bone via remodeling and will eventually resorb, resulting in small, round perforations in the external surface of the parietals (Brickley, 2018). The level of response in all individuals is not the same. Age influences the degree of diploë expansion, as younger individuals are sensitive to a lower stimulus threshold and have a higher capacity for adaptive elasticity and plasticity (Brickley, 2018; O'Donnell et al., 2020). It is important to note that bone marrow expansion and remodeling are not the primary responses to anemia but are a fallback option when less energetically expensive mechanisms fail to re-establish homeostasis (Walker et al., 2009).

Although a number of conditions have been attributed as causal factors for PH, such as chronic scalp infections and scurvy, anemia seems the most likely explanation in most situations based on modern clinical cases (Walker et al., 2009). Anemias fall into two main categories: hereditary and acquired. Acquired anemias may be traced to dietary deficiencies, parasitic siphoning of nutrients, or a trade-off response to disease burden (Beatrice and Soler, 2016). Acquired anemias are substantially more common than genetically inherited anemias (Walker et al., 2009: 110). Although many researchers specifically indicate iron-deficiency anemia as the probable culprit for PH lesions, Walker and colleagues (2009) argue that this does not make biological sense as a body lacking iron cannot increase red blood cell production. Instead, they suggest that anemias caused by premature or increased cell death (hemolysis) or ineffective red blood cell production are likelier causes that iron-deficiency anemia. Additionally, low-grade anemia would not result in the extreme response that PH represents. However, lower respiratory tract infections could exacerbate pre-existing anemia and lead to the development of PH. This does not mean that all instances of PH can be traced to lower respiratory infections, but that they might be an important, linked factor to consider. Due to the wide array of potential explanations and variety of anemia types linked to PH expression, this paleopathology is considered a non-specific indicator of metabolic stress.

Scoring of PH in this study was ranked on a scale of 0 to 4, with 0 indicating absence of the condition. A score of 1 represents small, barely discernible porosity, a score of 2 designates notable porosity, a score of 3 represents a progression of porosity towards coalescence, and a score of 4 signifies “coalescing foramina and expansive changes” (Beatrice and Soler, 2016: 1167). When assigning scores, I was relatively conservative and therefore consider anything above a score of 0 as sure presence of the trait. Additionally, any visualization of PH, however minute, does represent a notable energetic drain by an underlying condition and is thus determined to be worth documentation and inclusion in analysis.

Cribra orbitalia presents as the same localized porosity/foramina as porotic hyperostosis, but inside the thin bone of the superior orbits. The term cribra orbitalia (CO) was first used by Welcker in 1888 and was assumed to be a racially specific trait (Cole and Waldron, 2019). The location of CO is significant because the periosteum here is much more loosely attached to the bone than the periosteum throughout the rest of the body and the bone of the orbital roof is extremely thin (Brickley, 2018; Cole and Waldron, 2019: 618). Despite both PH and CO displaying similar size and types of porosity, it is unlikely that the two processes reflect the same underlying condition. The etiology of PH is understood to be linked to marrow and diploë expansion, but this same adaptive mechanism would not make sense in the orbits; the amount of diploë and marrow is quite insignificant and would not be worth the energetic investment (Cole and

Waldron, 2019). Despite this, many scholars still argue that CO is a precursor to PH (e.g., Stuart-Macadam; 1989; Wapler et al., 2004), perhaps because both pathologies can occasionally present together and look highly similar. This might explain the higher frequencies of CO when compared to PH, but it does not seem to reconcile that many individuals with PH do not have active or healed CO (Rivera and Lahr, 2017; Walker et al., 2009).

Alternatively, pathologies such as scurvy, rickets, heightened orbital blood pressure, and trauma that causes bleeding in the orbit have been documented as causing porosity in the orbital roof (Cole and Waldron, 2019; Griffeth et al., 1997; Ortner, 2003; Wolter, 1979). Any cause of bleeding in the orbits can distance the periosteum from the underlying bone and in the process of healing, highly vascularized newly formed bone can perforate and create the identifiable porosity of CO (Brickley and Ives, 2006; Rivera and Lahr, 2017; Schultz, 2001; Woo and Kim, 1997). Similar to PH, then, CO can be considered a non-specific indicator of biological stress because without significant, intrusive testing, it may not be possible to determine the exact cause of CO, but it is clear that CO is an indicator of a chronic underlying issue. Only crania with the majority of at least one orbit preserved were scored for CO, and the degree of severity was scored on the same scale as used for PH.

Periosteal Reactions

Periosteal reactions are new bone formations "produced by the periosteum in response to a range of conditions, including trauma, metabolic disease, and infection" (Gamble and Bentley, 2022: 20). Discussions of new lamellar bone formation primarily use the terms periostitis, periostosis, and periosteal reaction. In this section, I explain the differences between the three and discuss etiology, and the information that can be gleaned from its study. Most commonly, periostitis and periosteal reaction are used synonymously with each other. Periostitis specifically refers to an inflammation of the periosteum due to an infection that can affect the outermost layer of the cortical bone (Ortner, 2003; Pilloud and Schwitalla, 2020). In contrast, periostosis seems to refer to the same inflammation but is an umbrella term that reflects the array of underlying causes, beyond infection, for inflammation and new bone deposition (Klaus, 2017; Roberts, 2019). For this reason, periostosis is a suitable synonym for periosteal reaction, but to prevent the conflation and confusion between periostitis/periostosis, I will rely on the term periosteal reaction throughout this dissertation.

Periosteal reactions (PR) are one of the most documented pathological lesions in archaeological remains (Klaus, 2014). Diseases such as scurvy, leprosy, treponemal disease, rickets, trauma, and a variety of infections can induce an inflammatory response within the periosteum. This response triggers new bone growth which can manifest as pitting, striations, and swaths of healed, plaque-like bone (Larsen, 2015; Roberts and Manchester, 2007; Roberts, 2019; Zhang et al., 2023). As with PH and CO, periosteal reactions are a non-specific indicator of a biological stressor due the wide range of potential causative factors. For this reason, studies of PR have been criticized as a way of essentially declaring 'I don't know what caused this periosteal bone formation' (Klaus, 2014: 296; Weston, 2008: 50). I do not deny that there is ambiguity and a general inability to pinpoint exact reasons for PR in an individual, but that does not mean that these metabolic stress markers do not provide useful information. The presence of PR indicates that the body was under metabolic duress. The formation of new bone is a biologically costly endeavor, and the body would not undergo this process if less energetically expensive trade-offs had not failed to maintain homeostasis.

PR can occur when the body experiences trauma, an infection, or disease that irritates the periosteum, altering osteoclastic and osteoblastic activity in the underlying bone (Pezo-Lanfranco et al., 2020). Anything that "breaks, tears, stretches or even touches" the periosteum can initiate this irritation, inflammation, and subsequent response (Marques et al., 2019; Weston, 2008: 49). Bones where the periosteum is extremely close to the skin surface, such as the anterior tibial shaft, are more likely to develop PR than other elements (Roberts, 2019). The most frequently documented location of PR is the tibia and has been linked to premature mortality, demonstrating the value of using this metabolic stress marker to learn about health patterns in the past (DeWitte, 2014; DeWitte and Stojanowski, 2015; DeWitte and Wood, 2008; Klaus, 2014; Quade and Gowland, 2021). The breaking down of bone and laying down of new, woven bone happens in a nonuniform way. Some areas of new bone may be thicker than others, the new bone surface may undulate, but it is rare that the periosteal reaction involves the entirety of the bone shaft (Roberts, 2019). New bone development is still typically localized even in cases of systemic infection (Betsinger et al., 2020; Ortner, 2003; Weston, 2012). Throughout the life course, the periosteum retains its ability to alter osteoclast and osteoblast activity, though it does become more tightly attached to the underlying bone and thins with the aging process (Allen et al., 2004; Gosman et al., 2011;

Marques and Matos, 2019; Wenaden et al., 2005). This change in periosteal biology alters the rate at which the periosteum can respond to stimuli, and the threshold at which a response is triggered increases with age.

In this project, tibiae with more than 50% of the shaft preserved were systematically examined for PR. Scoring of PR followed the seven-stage scoring method set forth by Steckel and colleagues (2006) (Fig. 4.8). The seven-stage scoring system is divided as follows:

1= absence of PR

2= clear longitudinal striations

3= minor patches of reactive bone not exceeding ¼ of the bone's surface

4= moderate bone involvement not exceeding ½ of the bone's surface

5= significant reaction involving ½ of the diaphysis and notable cortical expansion

6= stage 5 with the addition of a cloaca

7= severe cortical bone involvement and expansion leading to fracturing.

Due to a lack of a universally adopted scoring system, statistical methods only make a delineation between presence and absence, and do not make a distinction between the degrees of severity (Weston, 2008). To err on the side of caution, any score greater to or equal to a 3 will be considered as presence of PR. Additionally, due to high rates of inter-observer error in assessing healing versus active lesions, this distinction was not made to increase the power obtained from these results.

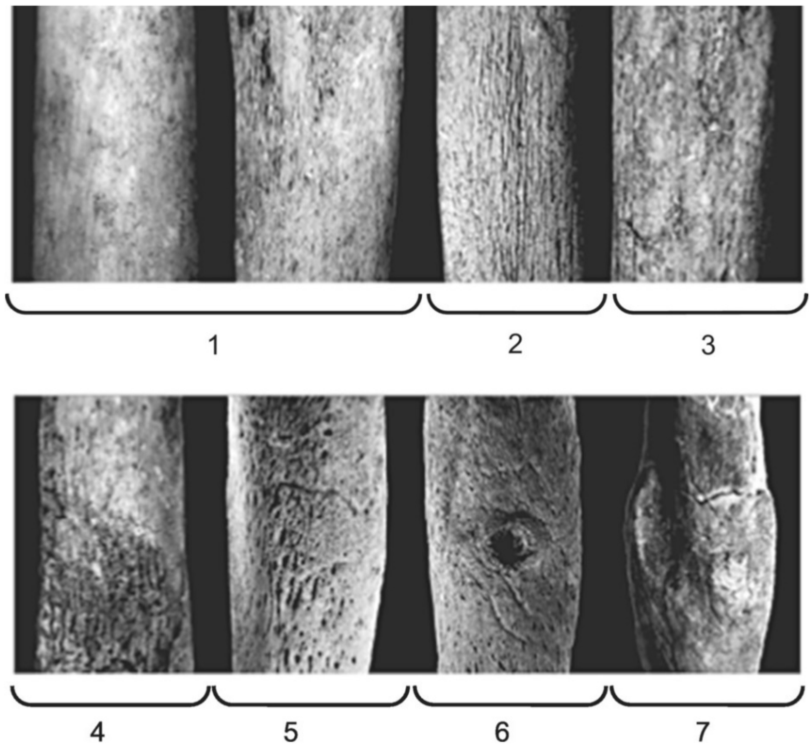


Figure 4.8. *Seven-stage scoring method for periosteal reactions as described by Steckel et al. (2006).*

Linear Enamel Hypoplasia

Examination of divergences in development in the teeth give an insight into stress during childhood. The crowns of anterior adult teeth develop between 4.5 months and 7.5 years, while the crowns of posterior teeth are not complete until the age of approximately 14 (Quade and Gowland, 2021: 53). Whereas bone remodels after growth perturbation, teeth do not remodel enamel and the defect is left as a permanent record of a stressful event (Blakey et al., 1994; Hutchinson and Larsen, 1988). Metabolic stressors interrupt the organized laying down of enamel, but in rare instances, enamel hypoplasias can also be attributed to genetic inheritance (Beatrice and Soler, 2016; Henriquez and Oxenham, 2020; Quade and Gowland, 2021). Due to the relatively low likelihood of generational enamel defects, hypoplasias will be assumed to be caused by metabolic stress. One extremely common cause of enamel hypoplasia is weaning stress, when infants switch from milk to perhaps a less nutritionally adequate and varied solid food diet (Blakey et al., 1994; Corruccini et al., 1985; Goodman and Rose, 1990; Huss-Ashmore et al., 1982; Rathbun, 1987). Enamel defects most commonly appear in the anterior dentition because of their strong link to weaning stress and the early age of formation of the crowns in anterior teeth (Beatrice and Soler, 2016). Enamel defects can manifest as pitting, horizontal grooves, or entire portions of enamel failing to form (Beatrice and Soler, 2016). This dissertation will focus on the most common form of enamel defect, linear enamel hypoplasia (LEH).

LEH is best described as one or more horizontal linear grooves, or furrows, on a tooth crown (Hillson, 2014; Ham et al., 2021). LEH represents a stressful event that required that energy be diverted away from enamel production to other processes more directly related to survival (Ham et al., 2021; Temple, 2019). LEH was identified macroscopically. Because recorded instances of LEH were large enough to detect without the aid of a microscope, the number of defects documented represents the lowest estimate of presence (i.e., there may be microscopic lesions not observed). Additionally, only individuals with LEH on multiple teeth will be considered as falling into the “presence” category for this trait. The reasoning behind these two recording thresholds is that enamel defects can also be linked to trauma or genetic inheritance, and the additional requirements to record LEH as present help ensure that the defects are most likely attributed to metabolic stress (Quade and Gowland, 2021). Although anterior teeth are more likely to develop enamel defects, both anterior and posterior dentition were assessed for LEH to compensate for tooth loss (antemortem and postmortem).

Carious Lesions

When eating, bacterial processes in the mouth and saliva aid in breaking down food but over time, unchecked bacterial fermentation of carbohydrates, particularly sugars, demineralizes the teeth and causes carious lesions that eat away at tooth enamel (Hillson, 2008; Pietrusewsky et al., 2014: 329). I use the term carious lesion to refer to the physical manifestation of the sugar fermentation process (the "cavity" in lay terms), because as made clear by Larsen (1997), the term "dental caries" refers to the *process* by which the hard tissue of the teeth is eaten away, not the lesion itself. The oral bacteria that cause carious lesions are not introduced from the external environment; bacterial strains such as *Streptococcus mutans* and *Lactobacillus acidophilus* exist naturally in the human mouth (Eng and Aldenderfer, 2017; Larsen et al., 1991; Lukacs, 1992). Variations in diet create bacterial waste products that range in acidity – the greater the acidity, the more quickly demineralization occurs, producing carious lesions (Dent, 2017; Ortner, 2003; Roberts and Manchester, 2007; Zoëga and Murphy, 2016: 578-579). For instance, plant-heavy carbohydrate-laden agricultural diets are high in sugar and cause higher frequencies of carious lesions than diversified foraging diets (Eng and Aldenderferm, 2017). Overall, a diet high in protein and low in carbohydrates and sugar is the least cariogenic type of food intake (Cucina et al., 2011; Turner, 1979; Lukacs, 2008; Larsen et al., 1991; Whittington, 1999).

A carious lesion can take a variety of forms/severity, from slight enamel opacity to perforation of the enamel, significant loss of tooth crown and even entire loss of the tooth (including root) itself (Larsen, 1997: 65). Beyond nutritional composition of diet, other factors that can influence the degree of severity of a carious lesion, and pattern of distribution within the mouth, include food texture, pre-existing enamel defects, trauma, systemic disease, use of fluoride, and crown morphology and size (Larsen, 1997). There is also some research that suggests that psychosocial stress can increase the risk of developing carious lesions (Dent, 2017). This, in addition to inequitable access in resources, can explain why there are differences in lesion rates between social classes in stratified groups (Cucina et al., 2011). For the UISC, lesion rates were documented for each individual as a frequency of number of total lesions divided by number of teeth present.

Statistical Analysis

Chi-square tests were used to look for sex-differences in PH and PR. Preservation of the orbits was generally low, and instances of observable CO were so rare that it is not a meaningful variable to include in most analyses. Logistic regression was used to look for relationships between age, birth location, and porotic hyperostosis. Based on Long (1997), the number of covariates that can be included in the logistic regression is linked to the sample size by the equation N=10*k/freq. where N=sample size, k=covariates, and frequency is the number of individuals exhibiting the condition divided by the number of individuals without the condition. When these parameters are applied to this specific sample, the inclusion of more than 2 covariates would necessitate a larger sample size. However, multiple logistic regressions were run to look for significant relationships between PR and PH (independently) and multiple demographic variables, such as age, birth location, occupation, etc. Fisher's exact tests were used to identify any differences in PH and PR between birth cohorts and also death cohorts. Sex differences in caries frequency, linear enamel hypoplasia, porotic hyperostosis, and periosteal reactions were investigated via an independent samples T-test for the former, and Fisher's exact tests for the three latter categories.

To determine whether there were differences in notch volume and NWI based on the presence of PR or PH, independent samples T-tests were utilized. These results were then confirmed via linear regression. The relationships between LEH and NWI and notch volume were also interrogated via independent samples T-tests, and the validity of these test results was checked using a Mann-Whitney non-parametric test. Linear regression was used to look for relationships between carious lesion frequency and notch volume and NWI (independently). Results from these tests were used to inform the building of a hierarchical multiple regression, in which demographic variables known to influence notch volume and NWI, such as birth location, are controlled for in the first step of the model. Finally, Fisher's exact tests were used to determine if the presence of PH or PR increased the likelihood of notch stenosis. As aforementioned, p-values below the threshold of .05 will be considered as significant in all statistical testing performed.

The Osteological Paradox

There are limits imposed on the inferences made from metabolic stress data. Understanding of these limitations comes primarily from the osteological paradox as outlined by Wood and colleagues (1992) who explain that all individuals lacking evidence of disease are not necessarily “healthy.” Osteological lesions or evidence of trade-offs may indicate that the individual had a strong enough immune system to deal with significant stressors, while those without lesions may have succumbed to disease too quickly to have formed a bone-altering response. Moreover, an individual may retain the osteological lesion for years after they have recovered from the initial stressor incident (Rinaldo et al., 2019). Therefore, the absence/presence of a singular trait is not enough to determine the health or stress level of an individual. For this reason, assessing for the presence of multiple conditions is necessary to get a more well-rounded understanding of health, stress, and disease.

4.5 MECHANICAL IMPACTS - ROBUSTICITY

There are two primary mechanisms of bone growth – modeling, which is initial bone development in an immature skeleton, and remodeling, in which already developed bone is altered during times of intense stress (Agarwal, 2021; Parfitt, 2003). Remodeling is the systematic way in which bone carries out maintenance in response to changes in environment, nutrition, and biomechanical input throughout the life course (Agarwal, 2021). Sometimes intense metabolic needs, such as lactation and pregnancy, require mobilization of calcium stores that can be accomplished via bone remodeling (Agarwal, 2021; Currey, 2003; Martin, 2003; Parfitt, 2003). Chronic mechanical loading can cause fatigue fractures on and around articular surfaces that are repaired through remodeling processes as well (Agarwal, 2021). Long bones have an outer periosteal surface and an inner endosteal surface upon which remodeling occurs, but remodeling also occurs at a third site, within the cortical bone (Agarwal, 2021; Seeman, 1997; Szulc and Seeman, 2009). Shifts in mechanical stress or prolonged bone loading stimulate bone remodeling to shore up osteological architecture (apposition) and prevent failure fractures (Nadell and Shaw, 2016). Studies of bone robusticity seek to quantify where bone remodeling and thickening has occurred and interpret what this reveals about movement and labor during the life course.

The term robusticity generally refers to the strength of a bone, particularly long bones, as is characterized by its shape and size (Stock and Shaw, 2007). While most consistently "robusticity" has been used to refer to the thickness of a long bone shaft in relation to its length, it has also been used to refer to measures of torsional strength and size of articular surfaces with reference to second moments of area (Bridges, 1989; Endo and Kimura, 1970; Lovejoy and Trinkaus, 1980; Pearson, 2000; Ruff et al., 1993; Ruff et al., 1994). For this dissertation, I quantify robusticity to qualify the relationship between long bone diameters (a way to discuss "thickness") and length.

Underlying statistical analysis of robusticity is the theory of bone functional adaptation (BFA). This generally accepted theory explains that when mechanical loading exceeds a bone's "design threshold" cellular processes orchestrate simultaneous resorption of old bone and deposition of new bone to create an altered shape better able to distribute and withstand mechanical loading (Agostini and Ross, 2011: 339). Long bones are particularly sensitive to stress forces with the mid-diaphyses of the distal elements experiencing peak bending stresses, and therefore representing the best area from which to obtain measurements (Carlson et al., 2007; Laffranchi et al., 2020; Nadell and Shaw, 2016; Patel et al., 2013; Robling et al., 2006; Wilks et al., 2009). Bipedal locomotion – walking and running – are the primary causes for repetitive loading stress on the lower long bones and thus analysis of these elements can indirectly reveal information about the landscape traversed during the life course (Sparacello et al., 2014). For instance, the shape of the tibial diaphysis in hockey players and runners is different due to distinctions in types of habitual movement, directionality, and strength of applied stress (Shaw and Stock, 2009). Traversing different types of landscapes also produces distinct movements that will map to long bone diaphysis, if to a lesser degree.

It is worth noting that analysis of cross-sectional diameter and length does have the limitation of not considering internal architecture of the bone, and thus cannot account for internal bone distribution (Laffranchi et al., 2020). However, the methods chosen do present a number of advantages. First, they are non-invasive which contributes to my desires to conduct research without enacting further harm on remains from already marginalized groups. Second, external measurements are economically efficient. Alternatives, such as computed tomography (CT) scanning and radiographs require expensive equipment not always available in the field. Robusticity measurements and ratios have been shown to be good proxies for results obtained via CT scanning and other means of examining interior cross-sections of the bone (Laffranchi et al., 2020; Ruff, 1987; Stock and Shaw, 2007; Wescott, 2006).

For long bones, the diaphyseal robusticity index (RI) has typically been calculated by the following formula following Martin and Saller (1956): 100*[(midshaft antero-posterior diameter (AP)+ midshaft medio-lateral diameter (ML))/maximum length]. Due to critiques that standardization by bone length does not properly control for differences in body mass, I choose to use an alternate equation suggested by Cole (1994) and Wescott (2006): RI= (100*(AP+ML))/humeral or femoral head diameter (HHD or FHD). Articular size is more strongly correlated with body mass than bone length, and thus standardization by femoral head diameter makes more sense (Lieberman et al., 2001; McHenry, 1988; Pearson, 2000; Ruff, 2000; Ruff et al., 1991). It is important to understand that the same formula used on different long bones will reveal unique information. For instance, the robusticity index for the lower long bones reflect bipedal movements – walking, running, and general locomotion patterns. However, the robusticity indices for the upper limbs, such as the humerus, will reveal more about labor specific movements and handedness. Directional asymmetry in the RI indicates that one side of the body is being loaded more heavily than the other side, which likely demonstrates a preference for a specific hand or foot (Plochocki, 2004). If the RI for all long bones is overall high, this may indicate ancestry to some degree, as groups that share evolutionary histories in cold climates have developed stockier overall builds, with robust diaphyses and epiphyses (Pearson, 2000).

Shape indices were also calculated for the humerus and the femur. Humeral midshaft shape (HMS) and femoral midshaft shape (FMS) were calculated by dividing the AP diameter by the ML diameter. This does not need to be standardized by body size or mass because the purpose of this index is purely to assess degree of platymeria (flatness). A shape index of 1.0 indicates that the shaft is not thicker in the AP or ML dimensions and is circular. A shape index greater that 1.0 indicates bending stress favoring the AP direction and a shape index of less than 1.0 indicates preferential loading in the ML direction (Wescott, 2006: 203). An FMS greater than 1 points towards high levels of mobility, while an HMS greater than 1 suggests high loading stress in a singular plane such as during hide scraping or spear use (Schmitt et al., 2003; Shaw et al., 2012; Temple et al., 2023). A more circular HMS (closer to or equal to one) indicates habitual tasks with multidirectional loading or torsional loading stress, like those generated during rowing (Schmitt et al., 2003; Shaw and Stock, 2009; Temple et al., 2023; Warden et al., 2014).

Statistical Analysis

Independent samples T-tests were used to look for sex-based differences in robusticity index and midshaft shape for both the femur and humerus. In all cases, the left side element was used wherever possible, with the right side only being used when the left side was missing or damaged. Due to concerns about unequal variances, a Kruskal-Wallis test (which makes no assumptions about score distribution and works on ranked means scores) was used instead of a one-way ANOVA to determine if FMS, FRI, HMS, and HRI significantly varied by both birth location schemes and by birth cohort. There are six birth cohorts and only two death cohorts because UISC individuals exhibit a greater spread in birth year than death year. Consequently, an independent samples T-test can be used to look for differences in FMS, FRI, HMS, and HRI between death cohorts, rather than a Kruskal-Wallis test. Further testing and attempts to control for the effects of multiple independent variables on the dependent variables were carried out via linear regression. To determine whether these four robusticity measures had any relationship to cause of death (COD), COD categories with fewer than five individuals were first omitted and then a Kruskal-Wallis test was run. The Kruskal-Wallis test is used heavily when conducting tests within the robusticity hypothesis to adapt the statistical work to small group sizes and deviations from normal with regard to skew and variance. For instance, the Kruskal-Wallis test is again used to investigate any relationship between occupation (scheme 1 and scheme 2) and the four robusticity measures. Post-hoc Mann-Whitney tests indicated between which occupations and robusticity measures a statistically significant relationship actually existed.

I ran tests for linearity with age at death and each of the individual robusticity measures. Only FMS and age exhibited a linear relationship. The strength of this relationship was assessed via linear regression. Again, I tested for any linear relationships between length of residency (first in the United States, and then specifically in California) and the four robusticity measures, of which only one pairing was significant. The strength of this singular pairing was again tested with the use of linear regression. Other linear relationships investigated via linear regression were NWI and HRI, and notch volume and HRI. The effect of occupation (both schemes) on notch volume was tested using the Kruskal-Wallis test and followed up with post-hoc pairwise Bonferroni-adjusted significance tests. Binary logistic regression examined the relationship of each of the robusticity measures and clinical notch stenosis, but only 10 individuals in the entire sample possessed NWIs that qualified as stenotic, so the strength of these tests is limited. Paired samples T-tests were employed to look for directional asymmetry (left versus right side) in the robusticity measures, as well as the level of asymmetry within each individual birth cohort and occupational group.

4.6 POSTCRANIAL NONMETRICS AND BIODISTANCE

Biodistance studies have a long history within the field of anthropology. The racial "science" that marred the field in the late eighteenth century boasted that cranial measurements indicated a pre-ordained hierarchy of racial groups based on faulty data/assumptions regarding endocranial capacity and intelligence (Blumenbach, 1775; Nikita, 2020). Even systems that we still use today and regard as quite secular, such as Linnaeus' binomial nomenclature system, were designed with human subdivisions ("subspecies" in Linnaeus' case) that were assumed as having a natural ranking (DiGangi and Hefner, 2013). Linnaeus' system was further expounded by the anatomist Blumenbach, who codified humans into 5 races – Caucasian, Mongoloid, Ethiopian, American, and Malayan (Brace, 2005; DiGangi and Hefner, 2013). To explain the heterogeneity of physiology, and justify the existence of race, two primary schools of thought existed until the 19^{th} century: monogenism and polygenism. Monogenists believed that all humans were descended from Adam and Eve and mobility and environmental changes lead to the array of skin colors that we see today (Brace, 2005; DiGangi and Hefner, 2013; Lovejoy, 1936). In contrast, polygenists believe that each race evolved independently, but at different points in time; the Caucasoid race was the oldest and thus the "most evolved" and the "Negroid" race was the youngest and least evolved (DiGangi and Hefner, 2013). With the rise of acceptance of evolutionary theory, the polygenism approach had become the most popular by the 19th century. However, both monogenists and polygenists used their belief system to justify the privilege given to one group and the subjugation bestowed upon others.

It was not until the development of the New Archaeology in the 1960s that the typology of racial divisions began to be seriously questioned in anthropology, and more nuanced questions about past population structures were asked (Buikstra, 1979; Corruccini, 1972; Lane and Sublett, 1972; Nikita, 2020). By the 20th century, anthropologists were now examining "racial groups" through the lens of a "coefficient of racial likeness" that used osteological metric traits to quantify the similarity between two groups and destabilizing racist studies from the past (e.g., Gould laying clear the bias in Morton's cranial capacity studies) (DiGangi and Hefner, 2013; Gould, 1978; Nikita, 2020). Anthropologists of the New Archaeology questioned the past reliance on typological methods, which inherently rely on assumptions that there are "natural" (i.e., via birth and heredity) differences in physical and cultural traits between groups (DiGangi and Hefner, 2013). This is not to say that the 20th century was without its stains. Social Darwinism, the notion that humans should also be subject to the edict "survival of the fittest," and eugenics, the drive to eradicate inferior genes from the population pool, led to the forced sterilization and increased reliance on asylums for unprivileged groups such as women, persons with disabilities, and racial minorities (DiGangi and Hefner, 2013; Graves, 2001; Shipman, 1994). Close to home for this researcher and dissertation, California alone forcibly sterilized over twenty-thousand individuals based on perceived mental underperformance, assumption that criminality was heritable, and desire to eliminate other disagreeable traits such as pauperism (DiGangi and Hefner, 2013; Larson, 1996; Marks, 2008; Suzuki and Knudtson, 1989).

By the late 1900s, anthropologists were starting to think about race quite differently. For instance, Montagu called race an “event,” something that was experienced rather than something inherently imbued upon the body (Armelagos and Goodman, 1998; DiGangi and Hefner, 2013; Gravlee, 2009; Harrison, 1995, 1998; Lieberman and Kirk, 2004). Part of this shift in thinking, was a new understanding of ancestry estimation. Rather than thinking categorically, and instead considering population-level trends, patterns in trait frequencies across ancestry groups are now understood in terms of evolutionary history (DiGangi and Hefner, 2013; Kennedy, 1995; Relethford, 2009). From this new consideration of ancestry rose the popularity of biodistance studies which recognize phenotypic traits “as a proxy for the genotype with the underlying assumption that skeletal phenotypic variation conveys phylogenetic information” (Nikita, 2020: 1; Relethford, 2016). Phenotypic traits can be metric or nonmetric and examined in the cranium, postcranium, and dentition. The assumption behind this approach is that people who are more physiologically similar will likely be more closely related genetically than those with dissimilar phenotypes (Barkmeier, 2020; Stojanowski and Schillaci, 2006).

Barkmeier (2020) lists five main guiding principles for biodistance analysis. First, we must assume that both gene flow and genetic drift are at work within populations in close geographic proximity to one another, influencing allele frequencies and gene expression. Second, a difficult assumption we must agree to is that the skeletal sample studied is an “accurate [representation] of the population in question over an extended period of time” (Barkmeier, 2020: 34). Third, variations in allele frequencies can be and are reflected in measurable phenotypic patterns. Fourth, environmental factors that influence allele frequencies are minimal compared to the contribution from genetic cues. Finally, genetic inheritance of expressed phenotypic traits is strong. This explains why there is such a large body of research investigating which traits show high levels of inheritance and which are more attributable to random change or environmental factors. The traits that demonstrate the highest levels of genetic inheritance tend to be localized in the cranium. Cranial nonmetric traits fall into two categories – morphoscopic and epigenetic variants (DiGangi and Hefner, 2013). Both are measured categorically as present/absent (or in some cases, scored by degree of expression), but morphoscopic traits are utilized for ancestry assessment in hopes of identifying an unknown individual, while epigenetic variants are more useful for analyzing relatedness (DiGangi and Hefner, 2013: 131-137).

Cranial and postcranial nonmetrics were documented; the former because they are the best studied and most reliable (only minimally influenced by climate, diet, or other environmental factors), and the latter due to cranial preservation limitations in the collection (Buikstra et al., 1990; Harvati and Weaver, 2006; Killgrove, 2009; Pietrusewsky, 2014; Relethford, 1994, 2001; Roseman, 2004; Roseman and Weaver, 2004; Smith et al., 2016). While it would be ideal to only use cranial nonmetric traits for biodistance analysis in this dissertation, crania were poorly preserved due to their apparent targeted use in the Stanford medical training courses to whom this collection previously belonged. Most individuals only retained a calotte; it was rare to see the orbits or the rest of the splanchnocranium preserved in this collection. Similarly, though dental nonmetric traits are also highly reliable, antemortem tooth loss and preservation issues associated with the craniofacial region make their use unsuitable as well. Therefore, due to this limitation, cranial and postcranial traits will be analyzed jointly. There is sufficient research to support success in utilizing postcranial nonmetrics for exploring population affinities, with the caveat that multiple bones are necessary to increase the accuracy and power of results (Holliday & Falsetti, 1999; Spiros & Hefner, 2020; Spradley, 2014; Winburn et al., 2022). Preservation of the postcranial elements was generally very good, with the exception of the vertebrae and extremities.

My avoidance of cranio*metric* traits is not without reason. I purposefully avoid craniometric measurements due to: (1) greater subjectivity to environmental influences, and (2) the racist history of these studies designed to "prove" inferior intellect of certain races and therefore justify subjugation of and violence towards certain groups of people (Dudzik and Kolatorowicz, 2016; Hooten, 1930). Following Buikstra and Ubelaker (1994), 31 nonmetric traits (Table 4.3) were recorded and scored as present/absent, or ordinally by degree of expression if the standardized scoring method called for this. All data were dichotomized as present/absent for analysis. Both sides of the body were analyzed and scored, but only the traits from the left side were used for statistical analyses except in cases where left side elements were unavailable (in the manner of Swenson, 2022).

The full list of nonmetric traits that were scored can be found below in Table 4.3. The list of traits used in the actual biodistance analysis (Table 4.4) is much shorter due to a multi-level filtering process. First, traits that were unobservable for over 50% of the sample population were disregarded. Second, traits that showed significant sex bias were eliminated from the analysis. In this case, only the third trochanter trait was filtered out by this requirement. Finally, traits that showed a link between presence and age at death were eliminated (only the parietal foramen). While both left and right sides were scored for nonmetric traits, due to concerns about duplication and overestimation of expression, only the left side of bilateral traits were included in final analysis. Additionally, due to the small nature of the sample size, statistical results have higher power when converted into dichotomous (present/absent), rather than scores associated with version of expression. Therefore, all scores that could be converted into binary scores were (parameters of "presence" are defined in Table 4.4), and those that could not be translated were omitted from this analytical process but retained for later aggregation into a larger population.

Table 4.3. *Full list of cranial and postcranial nonmetric traits recorded for each individual following standards set by Buikstra and Ubelaker (1994).*

Cranial Nonmetric Traits	Postcranial Traits
Metopic suture	*Atlas bridging*
Supraorbital notch/foramen	*Accessory transverse foramina in C7*
Infraorbital suture	*Septal aperture of the humerus*
Multiple infraorbital foramina	*Suprascapular foramen or notch*
Zygomatico-facial foramina	*Unfused acromial epiphysis*
Parietal foramen	*Sternal foramen*
Sutural bones (and location)	*Allen's fossa*
Inca bone	*Third trochanter*
Condylar canal	*Vastus notch*
Divided hypoglossal canal	*Squatting facets at distal tibia or talus*
Direction of flexure for superior sagittal sulcus	
Incomplete foramen ovale	
Incomplete foramen spinosum	
Pterygo-spinous bridge or spur	
Pterygo-alar bridge or spur	
Tympanic dehiscence	
Auditory exostosis	
Mastoid foramen	
Mental foramen number	
Mandibular torus	
Mylohyoid bridge	

Table 4.4. *List of nonmetric traits that passed through all filters. Squatting facets were omitted in final analyses due to a concern that they were linked more to behavior than genetics.*

	Trait	Minimum Score for Presence	Absence	Presence
Cranial Traits	Metopic Suture	*0-absent, 1=partial, 2=complete* Scores 1 & 2 considered as "presence"	96.1%	3.9%
	L Coronal Ossicle	Initially scored as dichotomous, scores remain the same	98.6%	1.4%
	Bregma	Initially scored as dichotomous, scores remain the same	98.6%	1.4%
	Sagittal Ossicle	Initially scored as dichotomous, scores remain the same	96.6%	3.4%
	Apical	Initially scored as dichotomous, scores remain the same	82.4%	17.6%
	L Lambdoidal Ossicle (Fig. 4.9)	Initially scored as dichotomous, scores remain the same	80.3%	19.7%
Postcranial Traits	L Septal Aperture (Fig. 4.11)	*0=absent; 1=small foramen, pinhole only; 2=true perforation* Scores 1 & 2 considered as presence	90.5%	9.5%
	L Suprascapular Foramen (Fig. 4.10)	*0=absent, 1=notch, 2=foramen, 3=spur/notch; 4=large concavity* Scores 2+ considered as presence	60.1%	31.9%
	L Unfused Acromial Epiphysis	*0=absent (fully fused); 1= partial fusion; 2=open (unfused)* Scores 1 & 2 considered as presence	96.9%	3.1%
	L Allen's Fossa/Poirier's Facet (Figs. 4.12 & 4.13)	*0=absent, 1=fossa, 2=plaque, 3= Poirier's facet, 4= Allen's fossa & Poirier's facet, 5= AF, PF, and plaque* Scores 3+ considered as presence	72.0%	28.0%
	L Vastus Notch (Fig. 4.14)	Initially scored as dichotomous, scores remain the same	69.1%	30.9%
	L Tibial Squatting Facet	*0=absent, 1=medial, 2=lateral; 3=lateral & medial* Scores 1+ considered as presence	67.3%	32.7%
	L Talar Squatting Facet	*0=absent, 1=medial, 2=lateral; 3=lateral & medial* Scores 1+ considered as presence	73.7%	26.3%

Note: *Presence/absence frequencies are calculated from the individuals in which the trait was possible to be observed.*

Figure 4.9. *Example of a right lambdoidal ossicle in UISC-1403.*

Figure 4.10. *Suprascapular notches in UISC-1006. This is a low-level expression and would be scored as "absence" for the suprascapular foramen trait.*

Figure 4.11 (Left). *Pinhole septal aperture in the right humerus of UISC-1005.*

Figure 4.12 (Right). *Minor expression of Allen's fossa in right femur of UISC-1589.*

Figure 4.13. *Poirier's facet (left) and plaque (right) formations in UISC-1005.*

Figure 4.14. *Presence of osteophytes and vastus notch on the patella of UISC-998.*

Statistical Analysis

Prior to running any statistical analyses, nonmetric traits must be sent through several filters to determine which have the most potential to contribute to a reliable genetic model. First, I eliminated any traits which were unobservable for over 50% of individuals in the sample. The second and third filters eliminated traits that demonstrated a sex-bias via Fisher's Exact Test and an age-bias (Box-Tidwell followed by binary logistic regression). This resulted in the final thirteen traits listed in Table 4.4. Imputation of the mode for each trait was used to fill in missing values, as most statistical tests designed for creating groups with high similarities cannot handle missing values. Individuals with more than six imputed values were eliminated from subsequent testing, as the reliability for that high proportion of imputed values is likely low. 2-step cluster analysis was used on the filtered individuals and nonmetric traits to generate a number of clusters with high intra-cluster, and low inter-cluster, homogeneity (i.e., statistically unique from one another).

To answer the question of whether assigned racial categories are meaningful in any way, a Fisher's Exact Test was used to test the significance of each (post-filtering) nonmetric trait with respect to assigned race and then to the generated cluster groups. To strengthen confidence in this test, a Pearson Correlation Test was also run to look for an association between assigned racial groups and membership to the generated clusters.

With these new cluster groups, a degree of exploratory analysis was carried out using one-way ANOVA testing to look for relationships to FMS, FRI, HRI, stature, and length of residence in CA. A Kruskal-Wallis Test was used for the same type of exploratory testing for HMS and residence in the U.S. with respect to the cluster groups, due to these variables not meeting all the required assumptions warranted by ANOVA (they failed the Leven's Test for Equality of Variances). The final aspect of exploratory analysis was carried out via binary logistic regression to investigate any potential association between the cluster groups and presence of PR or PH. One-way ANOVA and linear regression were used to validate one another when examining whether the phenotypically similar cluster groups had any notable relationship to notch volume or NWI. Had any significance been detected, a further step would have been taken by running a hierarchical multiple regression to control for confounding variables, such as stature, but this step was unnecessary given the results of the previous tests.

4.7 CONCLUSION

To conclude, the osteological methods employed in this work were chosen to: (1) test a specific hypothesis, and (2) to be as minimally invasive as possible. For instance, there are better ways of characterizing robusticity of the bone, such as via a cross-sectional view, but this would cause damage to the bone and cause further harm to the individuals in the collection. I seek to answer research questions in the most efficient way possible, while not exacerbating the preservation issues that already exist. Due to racial and sex asymmetry in the sample population, statistical tests will include both parametric and non-parametric testing, but the basis for employing each test will be explained more extensively in the following chapter.

Chapter 5: Results of Hypothesis Testing

5.1 INTRODUCTION

In this chapter, I will cover in depth the statistical tests used to evaluate the following hypotheses that are at the heart of this dissertation:

1. The development of a stenotic (abnormally narrow) notch is linked to experiences of systemic, metabolic stress.
2. The etiology of a stenotic intercondylar notch is linked to experiences of habitual mechanical stress.
3. Notch size is linked to genetic factors.

A potential fourth hypothesis is that the answer to the question of "What determines notch size?" is a combination of some or all of these factors. I begin the chapter by first establishing which control (demographic) variables have a secular relationship to notch volume and NWI. It is important to determine whether any of these variables need to be controlled for so that the variables of primary focus in these hypotheses can be tested for a statistically significant impact free from confounding relationships. Some of these demographic variables are redundant (i.e., the two birth location schemes). A part of what is being tested, apart from whether they might obscure another more pertinent association, is which variable is a better or stronger statistical representation of some aspect of an individual's history. In this groundwork, I establish which variables will continue to be included in analysis of statistical testing and considered in all subsequent model building.

From this point on in the dissertation, I will refer to a set of variables as “base” variables. I use this concept to describe variables that aid in establishing a baseline understanding of the UISC sample population. While the terms of demographic and control variables are widely used, neither of these sufficiently suits my needs. Some of the variables discussed do not fit the definition of a demographic variable, and not all have significant relationships with the variables of focus and need to be controlled for. Thus, I use the term “base” variables to refer to those that may influence hypothetical relationships without being central to the research questions or falling neatly into the category of demographic variables.

After establishing “base” variables to be included as covariates, I work through hypothesis testing. In each section of this chapter, I begin with some exploratory testing. I investigate whether the hypothesis-related variables have any notable relationships with the “base” variables. From there, I then look at how the hypothesis-related variables are correlated with, if at all, notch volume and NWI. In the penultimate section of this chapter, I take all of the significant variables and test interaction terms to build a strong model that explains as much variance in notch volume as possible. Implications of results from this section will be discussed in depth in Chapter 6.

5.2 THE INTERCONDYLAR NOTCH AND ITS RELATIONSHIP TO “BASE” VARIABLES

In this section, I detail the statistical tests designed to identify relationships between “base” variables, variables central to the hypotheses (e.g., robusticity index), and present the results. While the variable I am most concerned with is notch volume, I perform the same tests with respect to NWI for two reasons: (1) to make sure my results are comparable to the current literature, which predominantly utilizes NWI as the quantification measurement for the intercondylar notch, and (2) to test whether NWI and notch volume are redundant measures. In other words, if the same results are obtained from NWI and notch volume, there is no reason to forgo the current favored method for this more laborious one. However, if the results are different, then I must conclude that notch volume is measuring something that NWI is not, bolstering the argument that notch volume is a stronger quantification of intercondylar notch physiology.

For both NWI and notch volume, the potential confounding variables that were investigated include:

- Sex
- Stature
- Age at death
- Cause of death

These variables are considered as potential confounders due to a perceived lack of relationship to the three hypotheses being tested. However, they may still have an impact on notch size due to factors such as body size proportionality or decrease in capacity for plasticity over the life course. Consequently, it is important to determine if these variables must be controlled for during subsequent testing and model building. Conversely, other variables that may have a direct influence on the outcomes of the central hypotheses, categorized as “base” variables, and evaluated as independent variables, include:

- Length of residence within California (CA)
- Length of residence within the United States
- Race
- Birth cohort
- Death cohort
- Occupation (Schemes 1 and 2 as defined in the Methods chapter)
- Birth Location (Schemes 1 and 2 as defined in the Methods chapter)

It is also conceivable that some of these factors will be viable independent variables in the testing of some hypotheses, while only needing to be controlled for in the testing of others. Different relationships are examined with respect to each hypothesis and therefore the importance of each of the aforementioned variables may fluctuate depending on the context.

Results pertaining to these variables will be presented concurrently for both NWI and notch volume. It is important to note that for all statistical tests, the data were checked regarding test-specific assumptions. A few instances of assumption violation are why I use non-parametric tests, such as the Kruskal-Wallis test, rather than its parametric counterpart (ANOVA) in some circumstances. In particular, due to the small group sizes in the occupation, birth origin, and cause of death schemes, homogeneity of variance is a concern and cause for the use of statistical testing that is better able to withstand deviations from normality. Moreover, linear regression tests omit one notch volume as it was classified as a significant outlier by existing three standard deviations away from the mean. No other outliers were detected.

In the overall documented-UISC sample, which included those with femora from which a volume could not be calculated, NWI had no association with sex (t=.047, p=.962), while notch volume did indeed indicate a relationship to sex (t=7.308, p<.001). In the subsample with at least one preserved femur, these patterns held stable (NWI: t=.234, p=.815; notch volume: t=5.294, p<.001). Since sex is assumed to be a proxy for body size because males are typically larger than females in our species, stature was tested next as this is also a proxy for the same measure. Relationships between notch volume or NWI and stature were investigated via linear regression. Notch volume (ß=.506, p<.001) was highly associated with stature, but NWI was not (ß=.125, p=.136). If stature is measuring the same biological feature as the sex variable, overall body size, then it is logical that the results from both t-tests would match. Moreover, NWI by its property of being a ratio, eliminates the influence of body size and therefore should not be related to sex or stature. In summation, sex in itself is not a confounding variable, but body size is. Sex is, in fact, just measuring body size (represented by stature). NWI corelates with neither sex nor body size, but notch volume correlates with both. Therefore, I will not control for sex, but will control for stature when examining notch volume.

The next variable of interest is age at death. There is a concern that the intercondylar notch narrows over the life course, though overall shape change may negate this effect on the volume (e.g., Hirtler et al., 2016). Linear regression results indicate that notch volume is not in fact significantly impacted by age (ß=-.115, p=.119) and neither is NWI (ß=-.063, p=.406). Instances of notch narrowing throughout the aging process, then, may be mirrored in bicondylar breadth and therefore eliminated in the calculation of NWI, or these trends may be culturally or contextually dependent. In either case, secular change due to the aging process is not a concern in this study and this variable does not need to be controlled for with respect to volume or NWI in subsequent statistical testing.

Lengths of residence in the United States and CA were calculated and interrogated with respect to notch volume and NWI due to a concern that people who had more recently moved to a different geographical – and cultural – context might not yet have had time to exhibit a biologically plastic response to new patterns in movement and labor. Linear regression testing shows that length of residence in the United States is not statistically significant with respect to NWI (ß=-.033, p=.742) or notch volume (ß=-.011, p=.911), but length of residence in California specifically has a significant relationship with both (NWI: ß=-.230, p=.016; notch volume: ß=-.283, p=.002). One potential explanation for this phenomenon is that average length of residence in CA (37.47 years) was significantly shorter (p<.001) than average length of residence in the U.S. overall (57.78 years). The variance between these two variables was not statistically different (p=.13) and is not an important consideration in this outcome. Therefore, these results bolster the hypothesis that change in living context does have a biological effect and should be controlled for.

Race is examined as a variable of interest not to validate its biological reality, but to acknowledge that assigned race may reflect ancestry to a degree and therefore could incorporate genetic differences in a limited way. In other words, groups of people have different evolutionary histories and may have a natural propensity for larger notches, much in the way that groups living near the equator tend to grow to a greater height than individuals in the colder regions near the poles. Moreover, people of different assigned races may have had different life experiences, resulting in unique morphological outcomes. Kruskal-Wallis test results indicate that the assigned racial categories listed on birth certificates have no statistically significant relationship to NWI (Kruskal-Wallis H=.049, p=.997) or to notch volume (Kruskal-Wallis H=3.610, p=.307). The results of these tests should be interpreted as having low statistical power, as the racial group attributed as "Whites" vastly outnumbers individuals in the other three racial groupings (Asian, Brown, Black). This aspect of testing is also limited by known differences in levels of genetic diversity among ancestral groups; people of African descent are known to have higher genetic diversity than those of European descent, for example (e.g., Gomez et al., 2014). This question of ancestry and the impact of genetics on the distal femur will be unpacked in a more robust way in Section 5.5 in which nonmetric genetic markers are used to create clusters of phenotypically similar people. These tests indicate that assigned racial category is not a necessary variable for which to control.

Originally, the variables of birth and death cohort were hypothesized as redundant, assumed to be different ways of examining length of lived experience during a particular historical context. The primary distinction I drew between the two was scale; because these individuals all passed away during a much more concentrated time period (1929-1952) as opposed to the more greatly dispersed birth years (1842-1910), death cohorts allowed for aggregation of these individuals into larger groups that is less achievable with birth cohorts. However, if these two groups are measures of a synonymous context, lived historical period, then there should be a significant association between the two. A Fisher's Exact test indicates that this is not the case and there is not a statistically notable relationship between birth cohort and death cohort (p=.321). The implication of this result is that individuals born during a similar time period are not experiencing the same lifespan, highlighting a diversity of life chances perhaps not expected due to the homogeneity of socioeconomic status within this population. Considering Riffe and colleagues' (2017) discussion of building a complex understanding of "demographic time" using both types of cohorts in conjunction with lifespan, I argue that the cohorts used in this context reflect *distinct segments* of the life experience. Individuals grouped into the same birth cohort likely existed in a similar historical sociocultural context as one another in formative years of life, while individuals grouped in the same death cohort may have experienced a similar context during adult years of life. Thus, the deviation between the two is less about scale, and more about portion of life in focus.

Divergence in statistical results involving birth and death cohort support the conclusion that these variables are not synonymous. For instance, a Kruskal-Wallis test indicates that birth cohort was not a variable of significance for NWI (Kruskal-Wallis H=1.847, p=.870) or notch volume (Kruskal-Wallis H=5.307, p=.380). Contrary to this, an independent samples t-test demonstrates that death cohort is statistically insignificant to NWI (t=-.100, p=.921), but quite meaningful to notch volume (t=2.487, p=.014).

Dissimilarity of results lends support to the notion that birth and death cohorts are not redundant variables. However, it is also possible that differences in historical labor practices (i.e., gender norms) may have not been statistically apparent over the smaller spans of time represented by the birth cohorts, but become manifest over the longer spans of time seen in the death cohorts. Death cohort is therefore a variable of note for subsequent statistical tests.

Cause of death (COD) constitutes a variable worth investigating because health conditions may be linked to notch narrowing as an unknown side effect. The Kruskal-Wallis non-parametric test determined that only four COD categories met the minimum sample size to be included in the statistical model: cardiovascular disease, malignant neoplasms, infectious and parasitic diseases, and respiratory infections. For these four groups, results indicate that there is no meaningful relationship between any of these diagnoses and outcomes for NWI (Kruskal-Wallis H=.878, p=.831) or notch volume (Kruskal-Wallis H=2.224, p=.527).

The two occupational categorization schemes used in this dissertation are intended to be a way of representing daily labor type and level. Occupation Scheme 1 uses narrow categories designated by the Bureau of Labor Statistics. Occupation Scheme 2 aggregates these specific categories into larger groups based on relative intensity level. While subjective to a degree, few would agree with classifying a legal assistant and a farmer in the same labor intensity bracket. It is expected that this will need to be a variable for which I control when testing for relationships between NWI/notch volume and other variables of note. Kruskal-Wallis (KW) testing seems to validate this assumption as shown in Table 5.1 below. For Occupation Scheme 1, KW parameters only deemed eight groups as satisfactory to include in testing: Inmate (in home); building and grounds cleaning and maintenance occupations; food preparation and serving related occupations; sales and related occupations; construction and extraction occupations; farming, fishing, and forestry occupations; production occupations; "laborer." These occupational groups showed no notable relationship to NWI (p=.674) but a very strong one (p=.006) with notch volume. Post hoc Mann-Whitney testing with a Bonferroni correction indicated that the pairwise relationships contributing to this significant p-value are: Building and grounds cleaning and maintenance occupations (hereafter abbreviated as "maintenance"), "laborer" (p=.005), maintenance-farming, fishing, and forestry occupations (p=.034), and maintenance-inmate (p=.015). Notch volume means of the maintenance category are significantly smaller than the means of the other included occupations. This result will be explored further in the discussion carried out in Chapter 6.

Table 5.1. *Test-specific and significance values for* ***occupational schemes*** *1 & 2 in relation to NWI and notch volume.*

	NWI		**Notch Volume**	
	Kruskal-Wallis H	**p-value**	**Kruskal-Wallis H**	**p-value**
Occupation Scheme 1	4.889	.674	20.001	.006*
Occupation Scheme 2	3.981	.552	14.073	.015*

**Significant at the .05 level*

All groups in Occupation Scheme 2 are large enough by Kruskal-Wallis test parameters to be included. Once again, the relationship to NWI was very weak (p=.552) while the association with notch volume was statistically significant (p=.015). Post hoc Bonferroni-corrected Mann-Whitney tests show only one significant pairwise comparison (p=.014) in this scheme: the highest ranked labor intensity group (occupations 2/5/6: maintenance, construction/extraction, forestry/farming/fishing) and one of the lowest labor level groups (4/9/12/13: Sales, architecture/engineering, personal care/service, healthcare/technical occupations). From these tests, it seems that the higher the labor intensity, the lower the notch volume. To further investigate this, the Occupation Scheme 2 categories were further aggregated into two groups: the half of the occupation categories with the lowest labor intensity comprised one group, and the half with the highest intensity another. An independent samples t-test indicated no significant variance (p=.939) in notch volume between the groups, but a significant difference in mean volume (p=.008). The categories representing the occupations with the highest labor intensity had a notch volume average of 16,376.74mm^3, while the lowest intensity occupations had an average of 18,233.31mm^3. These results support the noted trend of a negative correlation between labor intensity and notch volume and indicate that occupation needs to be corrected for when tests involve notch volume, but not NWI.

Two birth location schemes with nearly the same number of groups, but different methods of categorization, are utilized in this research. Birth Location Scheme 1 breaks up nation of origin by individual country, while Birth Location Scheme 2 groups countries by geographic region (e.g., Northern Europe) in an attempt to get at regional patterns that transcend national boundaries. The United States is broken up into regions in both schemes. As indicated in Table 5.2, the only insignificant KW test value was that which reflected the relationship between NWI and Birth Location Scheme 2. Since both Birth Location schemes are significant in relation to notch volume, I will include only

Birth Location 1 as a covariate in robust model testing (Birth Location Scheme 2 will still be investigated to a degree) to make results comparable between NWI and notch volume.

Table 5.2. *Test and significance values for* ***birth location schemes*** *1 & 2 in relation to NWI and notch volume.*

	NWI		**Notch Volume**	
	Kruskal-Wallis H	**p-value**	**Kruskal-Wallis H**	**p-value**
Birth Location Scheme 1	18.631	.045*	26.438	.003*
Birth Location Scheme 2	14.689	.100	20.865	.013*

**Significant at the .05 level*

5.3 RESULTS PERTAINING TO HYPOTHESIS 1: METABOLIC STRESS

Before I present the results pertaining to metabolic stress markers and their relationship to notch size, it is important I address that this osteological category is the one most difficult to test. I cannot do robust, extensive statistical testing primarily due to preservation issues (i.e., unable to observe the necessary elements), but also a relative dearth of metabolic stress markers. For instance, only a very small proportion of individuals in the UISC have well-preserved orbits, making it near impossible to determine any meaningful relationships regarding cribra orbitalia. There are not enough complete datasets here to be confident in more thorough testing since tests like ANOVA have more stringent requirements of the data. The results discussed in this section, therefore, represent those for which the results have statistical power and produce generalizable outcomes.

First, I investigated whether there were any significant differences between sexes in caries frequency, LEH, PH, and PR presence. Sex-based asymmetry in any of these traits would reveal something about differences in experiences of biological stress, and also would indicate that this is a variable that needs to be accounted for (controlled for) in subsequent statistical testing and model generation. Levene's Test for equality of variances confirmed that the assumption of equal variances in caries frequency between sexes was upheld (F=.028, p=.867), and an independent samples t-test indicated no significant difference between these two groups (one-sided p=.141, two-sided p=.283). Due to limitations in cell count, chi-square testing was not a suitable technique for the categorical variables of LEH, PH, and PR presence. A Fisher-Freeman-Halton Exact Test, an extension of the well-known Fisher's Exact test with the ability to handle contingency tables beyond the standard 2x2, indicated no significant association (p=.123) between sex and LEH presence. Fisher's Exact tests also revealed no significant relationship between sex and PH (p=.308), nor sex and PR (p=0.122). Therefore, sex does not seem to have any notable impact on the four primary metabolic indicators discussed here and does not need to be controlled for.

Age and birth location were also interrogated as potential influences on presence of metabolic stress indicators. It is reasonable to inquire if over the life course an individual's risk of presenting with a metabolic stress indicator increases. It makes sense that an older individual has not only had more opportunity to become metabolically stressed, but also the strength of the immune system decreases with age, and therefore elderly individuals are more likely to exhibit evidence of biological stress. However, it is also possible that country of origin may be entangled with metabolic stress marker frequencies. Many of these individuals spent a notable portion of their childhood in a country other than the United States. Given that they were motivated enough to undertake the difficult task of travel and relocation, they may have been leaving a stressful environment or experienced a new level/type of stress after arrival to their new state of residence. To examine the potential association between age and birth location on PR and PH (Table 5.3), linear regression was utilized. No p-values were found to be significant at the .05 level.

Table 5.3. *Results of binary logistic regression tests investigating if* ***age*** *and* ***birth location*** *are associated with* ***periosteal reaction*** *or* ***porotic hyperostosis*** *presence. The only difference between the two simple models is which birth location scheme was employed.*

		Periosteal Reaction Presence	**Porotic Hyperostosis Presence**
		p-value	**p-value**
Model 1	*Age at Death*	.810	.309
	Birth Location 1	.974	.659
Model 2	*Age at Death*	.483	.591
	Birth Location 2	.758	.867

Additionally, I considered it a strong likelihood that historical time period, or rather the cumulative experience of living earlier or later in time, would impact the frequency of metabolic stress marker presence. To test this, I used Pearson chi-square and Fisher's Exact tests to look for differences in PR and PH regarding birth and death cohorts. Again, I underscore that PH and PR will be the most frequently referenced metabolic stress markers due to extremely limited observability of the other traits. The two death cohorts defined in this research are deaths between 1929-1939 (Death Cohort 1), and deaths between 1940-1952 (Death Cohort 2). According to the results of Fisher's Exact tests, these two death cohorts are significantly different with respect to PR frequency (p=.023), with Death Cohort 2 having higher rates of PR. Frequencies of PH did not vary significantly between these same cohorts (p=.114). The same tests were run again comparing birth cohorts to further interrogate the original assumption that birth and death cohorts are measures of the same factor – historically oriented lived-experience, a more nuanced version of an age at death variable. As outlined in the Methods chapter, birth cohorts are defined as follows:

- **Birth Cohort 1:** 1842-1852
- **Birth Cohort 2:** 1853-1863
- **Birth Cohort 3:** 1864-1874
- **Birth Cohort 4:** 1875-1885
- **Birth Cohort 5:** 1886-1896
- **Birth Cohort 6:** 1897-1910

Birth Cohort 6 was omitted from the following testing as it was too small a group to reveal anything meaningful. Perhaps surprisingly, neither PH (p=.490) nor PR (p=.799) frequency differed significantly by birth cohort. Once again, the divergence in these results hints at notable nuances in what these two variables – birth and death cohort – actually represent. Further, it is worth asking whether the difference seen in death cohort might relate to survivorship. Maybe someone who had PH as a child and survived, demonstrating greater overall health and ability to be resilient, tended to have a longer lifespan. Using logistic regression, I investigated whether there was a relationship between PH/PR expression and age. For PH and age of death, the p-value was .863, and for PR and age at death, the p-value was .843. In both cases, neither metabolic stress marker has anywhere close to a significant relationship with age at death. What this reveals is that, rather than an age-related change, there is a change through historical time periods. This pattern is telling us something about changes in socioeconomic context, with people living through later years experiencing a more burdensome, stressful context than those who died in an earlier period. It is also possible that later death date is correlated with longer lifespan, but this is not relevant to this analysis as lifespan is not correlated with the dependent variables.

For cause of death, only the categories of cardiovascular disease, malignant neoplasms, infectious and parasitic disease, and respiratory infections included sufficient subsamples to be included in this binary logistic regression. Again, the results indicated weak associations between COD and PR (p=0.442) and PH (p=0.250). The associations between occupation and PR/PH were even weaker and are summarized in Table 5.4 below. Death cohort, then, seems to be one of the only variables that shows any association with metabolic stress markers.

Table 5.4. *Exploratory analysis via binary logistic regression testing the potential presence between* ***PR/PH*** *and* ***occupation****.*

	Occupation Scheme 1	**Occupation Scheme 2 (aggregated groups)**
PR frequency	p=.961	p=.949
PH frequency	p=.910	p=.709

Before attempting more robust model building with the metabolic stress markers, I was interested in whether notch stenosis (binary variable scored as presence/absence) showed any association with PR or PH. Fisher's exact tests revealed that knees meeting the clinical definition of stenotic did not exhibit a strong relationship with PR (one-sided p=.237, two-sided p=.354) or PH (one-sided p=.243, two-sided p=.358). However, it should be noted that of the individuals with a preserved femur, only ten of the 186 individuals possessed a stenotic notch. It is possible that this frequency may be too small to detect any potential associations at this current juncture. Further tests are recommended upon later enlargement of the sample size.

To determine whether periosteal reaction presence has any independent relationship with notch volume, I must control for the "base" variables with which notch volume has previously demonstrated a significant association: sex, stature, length of residence in CA, death cohort, occupational schemes 1 and 2, and birth location schemes 1 and 2. However, it is not important to include all of these in the regression model, as some measures are redundant. For instance, both occupational schemes are a measure of the same variable – labor type. Since the they both are significant variables but redundant measures, I will include only occupational scheme 2 as this represents the aggregated labor categories (i.e., groups are larger) and therefore possesses greater statistical discerning power. Both birth location schema have fewer categories than the occupation 1 scheme, so I will run two different regressions and test which birth location scheme presents the strongest model and include whichever has greater predictive power in the final model. Further, previous hierarchical regression demonstrated that controlling for both sex and stature at the same time is unnecessary, likely because these are both related to body size. Stature, due to its continuous nature, is a stronger predictor variable than the binary variable of sex, so I will include the former rather than the latter in the following regression models. Therefore, the final demographic variables to be controlled for with respect to notch volume are stature, length of residence in CA, death cohort, occupation scheme 2, and birth scheme 2. Birth location scheme 2 was chosen to be included over birth location scheme 1 after aforementioned testing, as it offered greater explanatory power to the regression model.

Some of the major assumptions validated before carrying out hierarchical linear regression were those of homoscedasticity, lack of multicollinearity, independence of observations, and linearity. In the first hierarchical linear regression performed, the aforementioned "base" variables were included in step one of the model, and the periosteal reaction variable in the second step of the model, with notch volume as the dependent variable. The results are presented in Table 5.5. The model with only the "base" predictors alone (step 1) can explain approximately 36% of the variance in notch volume. The addition of periosteal reaction presence did not add any further predictive power to the model with only the "base" variables, with absolutely no change in R^2. Therefore, we can conclude that there is not a meaningful association between periosteal reaction presence and notch volume when other known significant covariates are controlled for.

Table 5.5. *Hierarchical linear regression model showing birth location, occupation, length of CA residence, stature, death cohort, and* ***periosteal reaction*** *presence as predictors* ***for notch volume.***

Variable	Cumulative		Simultaneous	
Step 1	**R^2-change**	**F-change**	**Standardized ß**	**p-value**
Occupation Scheme 2	.373	F(5,99)=11.801*	-.127	.145
Length of residence, CA			-.258	.005
Stature (w/adj. for old age)			.436	<.001
Death Cohort			-.194	.022
Birth Location Scheme 1			-.148	.074
Step 2				
Periosteal Reaction	.000	F(1,98)=.078**	.023	.781

*p<.001, **p=.781

The same hierarchical regression methods were utilized to test for an association between notch volume and porotic hyperostosis presence (Table 5.6). In this case, the addition of porotic hyperostosis presence as a covariate did increase the predictive power of the regression model significantly (p=.002). The step 2 model that includes relevant "base" variables and the added porotic hyperostosis covariate explains approximately 51% of variance in notch volume, a notable improvement over the previous model that included periosteal reaction presence as a predictor instead. In this case, the statistically significant improvement of the model after "base" factors are controlled for indicates that porotic hyperostosis presence does have a strong independent association with notch volume outcomes. The potential explanation and relevance for this relationship will be explored in the subsequent discussion chapter.

Table 5.6. *Hierarchical linear regression model showing birth location, occupation, length of CA residence, stature, death cohort, and* ***porotic hyperostosis*** *presence as predictors for* ***notch volume.***

Variable	**Cumulative**		**Simultaneous**	
Step 1	**R^2-change**	**F-change**	**Standardized ß**	**p-value**
Occupation Scheme 2	.440	F(5,76)=11.937*	-.230	.011
Length of residence, CA			-.238	.012
Stature (w/adj. for old age)			.459	<.001
Death Cohort			-.206	.014
Birth Location Scheme 1			-.175	.039
Step 2				
Porotic Hyperostosis	.071	F(1,75)=10.838**	.269	.002

*p<.001, **p=.002

Although most UISC individuals were missing a majority of their teeth, it is possible to glean some understanding of how caries frequency data relate to notch volume. However, upon attempting to run linear regression tests, it was clear that these data violate the assumption of homoscedasticity. The violation of this assumption does not mean that regression is impossible, but that it must be run via a different method that does not assume equality of variances. In this case, I ran a multiple regression with robust standard errors estimates. This method is limited in that it does not run model testing in a hierarchical manner but does still give reliable insight as to the relationship between caries frequency and notch volume. The results of this regression testing (Table 5.7) indicate that there is not a significant relationship between caries frequency and notch volume.

Table 5.7. *Regression with robust standard errors estimates including demographic variables and* ***caries frequency*** *as covariates influencing notch volume.*

Variable	ß	p-value
Length of residence, CA	3.810	.922
Occupation Scheme 2	-237.346	.565
Caries frequency	2160.118	.135
Stature (w/adj. for old age)	278.666	.001
Birth Location Scheme 1	183.297	.353
Death Cohort	-2330.052	.100

NWI is not the focus of this dissertation, but it is worth including in statistical analysis because it is the current method of choice for notch quantification in clinical studies. The following results are presented with the intention that this research, while contributing something new to the fields of anthropology and medicine, is also comparable to past and current research. I ran the same hierarchical regressions, and regression with robust standard error estimates, as performed for notch volume, and I present the results in the same order for ease of comparison. In the case of NWI, the "base" variables with significant relationships to NWI are slightly different, as this measure already seems to control for the effects of body size. These variables are length of residence in CA, both birth location schemes and both occupation schemes. As with notch volume, due to the greater statistical power of the aggregated groups in Occupation Scheme 2, I opted to exclude Occupation Scheme 1 as a covariate. Also, like notch volume regression tests, I tested models with each birth location scheme and included that which provided the highest predictive power.

The first in the series of hierarchical regression utilizes length of residence in CA, birth location scheme 1, and occupation scheme 2 as the step 1 filter variables and periosteal reaction presence as the step 2 variable of interest (Table 5.8). The addition of periosteal reaction into the regression model did not significantly improve the predictive power of the model (p=.362). The model with all four of these variables explains only approximately 13% of the variance in NWI, though the model itself is statistically significant (p=.010). Overall, these results indicate that the presence of periosteal reactions in an individual do not show a strong association with the outcome variable, NWI.

Table 5.8. *Hierarchical linear regression model showing birth location, occupation, length of CA residence, and* ***periosteal reaction*** *presence as predictors for NWI.*

Variable	Cumulative		Simultaneous	
Step 1	**R^2-change**	**F-change**	**Standardized ß**	**p-value**
Occupation Scheme 2	.119	F(3,98)=4.401*	-.014	.893
Length of residence, CA			-.308	.003
Birth Location Scheme 1			-.216	.027
Step 2				
Periosteal Reaction	.008	F(1,97)=.840**	.088	.362

*p=.006, **p=.362

The second hierarchical regression performed used the same "base" variables in step 1 and swapped out periosteal reaction presence for porotic hyperostosis presence in step 2. Once again, both forms of the model explain very little of the variance in NWI, with the better 4-predictor model explaining only about 10.2% of this variance. The regression model was not significant at the p=.05 level at either step 1 or step 2 (Table 5.9). The addition of porotic hyperostosis as a covariate increased the variance explained only by 1% and was not significant (p=.329), indicating that the presence of this metabolic stress marker does not have any bearing on NWI.

Table 5.9. *Hierarchical linear regression model showing birth location, occupation, length of CA residence, and* ***porotic hyperostosis*** *presence as predictors for NWI.*

Variable	Cumulative		Simultaneous	
Step 1	**R^2-change**	**F-change**	**Standardized ß**	**p-value**
Occupation Scheme 2	.090	F(3,75)=2.471*	-.101	.402
Length of residence, CA			-.233	.060
Birth Location Scheme 1			-.217	.059
Step 2				
Porotic Hyperostosis	.012	F(1,74)=.967**	.110	.329

*p=.068, **p=.329

Finally, regression with robust standard error estimates was used to test for an association between caries frequency and NWI. As expected from the lack of an association between other metabolic stress markers and NWI, caries frequency also appears to have no relationship to NWI (Table 5.10). The difference in results between notch volume and NWI alludes to the fact that these measures are not alternate ways of capturing the same biological variation. If this was the case, we would expect to see the same demographic variables (except for body size-related ones) showing strong relationships with both NWI and notch volume, as well as metabolic stress affecting both measures in the same way. Although not a strong association, notch volume is affected by metabolic stress in some way, as it has a significant relationship with porotic hyperostosis, and the related regression model accounts for over half the variance in notch volume. This model far exceeds any of the regression tests run with NWI as the dependent variable. NWI shows a dearth of significant relationships with any metabolic stress markers.

Table 5.10. *Regression with robust standard errors estimates including "base" variables and **caries frequency** as covariates influencing NWI.*

Variable	ß	p-value
Length of residence, CA	.001	.255
Occupation Scheme 2	.005	.354
Caries frequency	.031	.078
Birth Location Scheme 1	.000	.951

5.4 RESULTS PERTAINING TO HYPOTHESIS 2: MECHANICAL STRESS

I begin this section with summary statistics regarding mechanical stress measures before I investigate their specific relationships with notch volume and NWI. The mechanical stress measures of note are femoral robusticity index (FRI), femoral midshaft shape (FMS), humeral robusticity index (HRI), and humeral midshaft shape (HMS). These are defined in the methods chapter, but their meanings will be reiterated briefly. FRI is typically interpreted as a measure of general mobility level. The thickness of the bone, standardized by a measure of body size (in this case diameter of the femoral head), indicates level of mechanical loading over a long period of time. Simply put, the larger the FRI, the greater loading stress experienced by the bone throughout the life course. Since humans are bipedal, locomotion is the primary mode through which the femora experience loading stress, dubbed by the literature as "mobility." FMS, on the other hand, reveals information about directionality of the loading stress. FMS is the antero-posterior diameter divided by the mediolateral diameter of the midshaft. Therefore, a femur with an FMS near 1.0 has experienced primarily multidirectional movement. A bone with an FMS above 1.0 has experienced loading more in the antero-posterior direction, while below 1.0 represents loading mostly in the mediolateral direction.

Like FRI, HRI primarily indicates degree of mechanical loading when compared to other individuals (and to some degree evolutionary group history), and handedness when compared by side within the same individual. Given that the humerus is not typically a load bearing bone, it may be difficult to visualize how it might experience mechanical stress. Mechanical loading is often conceptualized as acting in the same direction as gravity, but this is rarely the case in the humerus of humans. Sports medicine studies that examine patterns in stress fractures shed some light on this topic. The two most common mechanical forces experienced by the humerus are torsional and bending forces (Jabran et al., 2018). Torsional forces occur primarily during throwing motions and are exemplified by the high frequency of spiral fractures in athletes like baseball players (Jones, 2006; Warden et al., 2019). These fractures frequently occur at the middle and distal end of the humerus (Jones, 2006). Bending forces are experienced when lifting heavy loads. Weightlifters, for example, experience humeral shaft stress (and fractures) via axial loading forces transferred from the elbow joint (Jabran et al., 2018; Jones, 2006). Overall, any type of movement causing repeated flexion of the bicep muscle or loading at the elbow will cause mechanical stress on the humerus that can impact HRI.

Another characterization of humeral stress is HMS. Temple and colleagues (2023) explain humeral midshaft shape similar to that of FMS; a more circular midshaft cross-section indicates multidirectional or rotational loading, as seen in throwing and rowing activities, and an accentuated anteroposterior dimension (AP) demonstrates unidirectional loading, as in spear-thrusting (393). In conducting prior research on this measure and its variability, I was not able to find any instances of groups (e.g., occupational or cultural) that demonstrate greater mediolateral (ML) dimensions than AP ones. This is likely due to most loading of the humerus happening in front of the body. In baseball, tennis (Bass et al., 2002), javelin, spear-throwing, and even lifting weights, all upper limb motions are happening in a forward motion or in front of the body. I did not encounter any recreational or occupational context in which loading stress was primarily exerted in the ML direction (but perhaps, the rare *Survivor* challenge?). All encountered literature seems to indicate that HMS is either near circular or enlarged in the AP dimension.

When looking for variables with meaningful relationships to these four robusticity measures, the most logical with which to start is sex. The interest in sex as a variable, in this case, is not due to a concern about sexual dimorphism skewing results. All four robusticity measures are a ratio of linear measurements essentially comparing the individual to itself, and inherently controlling for differences in body size. Rather, the interest stems from concern that gendered division of labor may play a role in creating asymmetry in robusticity measures. Results from the independent samples t-test pertaining to this hypothesis are shown below in Table 5.11. There were no statistically significant differences between males and females for any robusticity variable.

Table 5.11. *Chart summarizing the results of independent samples t-tests investigating sex-related asymmetry of robusticity measures.*

Measure	Sex	N	Mean	Std. Dev.	F	F-test p-value	t	df	t-test p-value
FRI	M	161	120.43	10.29	.001	.980	-.662	177	.509
	F	18	122.09	8.47					
FMS	M	163	.959	.104	.276	.600	-.712	181	.478
	F	20	.977	.106					
HRI	M	129	90.05	5.91	2.179	.142	.430	145	.668
	F	18	89.40	7.20					
HMS	M	132	.812	.071	.831	.363	1.243	148	.216
	R	18	.790	.049					

I next investigated whether birth location might influence the measures of focus in this section. Birth location might be an influential variable given different group evolutionary histories, which may predispose people to develop more robust or gracile bones. Additionally, historical patterns reiterate the tendency for those in the U.S. to discriminate against others based on their nation of origin. It is plausible that people of the same country or region might cluster in the same occupations due to a desire for community, or because they were barred from having other choices due to oppressive structures. Due to the small sizes of the groups split over the 11 birth location categories in scheme 1 and the 10 in scheme 2, a statistical method more robust to deviations from normality was necessary and for that reason, I employed the Kruskal-Wallis non-parametric test. For Birth Location Scheme 1, none of the robusticity measures were significantly related to birth location (FRI: p=.221; FMS: p=.149; HRI: p=.515; HMS: p=.431). These results held firm when running the same tests for Birth Location Scheme 2 (FRI: p=.118; FMS: p=.325; HRI: p=.515; HMS: p=.431). Birth location does not exert a significant influence on robusticity characteristics of the femur and humerus.

Kruskal-Wallis tests were used to examine whether birth cohort was related to these robusticity measures. The sixth birth cohort (1897-1910) was omitted from these analyses as it only included four individuals and therefore was too small to contribute anything meaningful to the results. None of the birth cohorts demonstrated any significant association with FRI (p=.622), FMS (p=.292), HRI (p=.822), or HMS (p=.987). These relationships were mirrored in death cohort (FRI: p=.369, FMS: p=.698, HRI: p=.656) except for humeral midshaft shape (p=.046). Like the statistical methods used in the metabolic stress section to validate this specific phenomenon of a significance in death cohort but not birth cohort, I used hierarchical regression to control for age. The goal is to make sure that death cohort is not reflecting change based on longevity and eliminate the possibility that age might be the cause of the significant result. This is probably not a considerable issue, as there was not a significant correlation between life span and death cohort (p=.059), but I include it nonetheless as extra assurance. After controlling for the effects of age (p=.882), death cohort (p=.047) still had a significant effect on HMS. This further bolsters the argument that death cohort is a distinct measure from birth cohort. Moreover, these results, combined with the significance of death cohort (but not birth cohort) to metabolic stress markers, indicate that experiences during adult life are more apparent postmortem than those during the formative years. Taken together, these patterns are a testament to the continued ability of bone to respond to mechanical and metabolic stressors throughout the life course.

Cause of death, via Kruskal-Wallis testing, also has no association with these robusticity measures (FRI: p=.306, FMS: p=.805. HRI: p=.872, HMS: p=.310). To reiterate from the previous section, these tests only include four cause of death categories (cardiovascular disease, malignant neoplasms, infectious and parasitic diseases, and respiratory infections) because the rest of the groupings are too small to meet the statistical test parameters. There did not seem to be a logical reason why cause of death and measures of robusticity would be linked, but this relationship was investigated regardless.

Next, the four robusticity measures were tested for relationships to both occupational schemes. The Kruskal-Wallis test revealed that FRI values varied significantly when grouped by Occupation Scheme 1 (p=.009) but not by FMS (p=.412), HRI (p=.394), or HMS (p=.495). Post-hoc Mann Whitney tests to determine exactly which occupational pairings are significantly different from one other indicate that there is something unique about the construction and extraction group. Table 5.12 summarizes the significant post-hoc tests and Figure 5.1 visually demonstrates the notably high FRI average of construction/extraction occupations compared to other groups.

Table 5.12. *Summary of only the significant post-hoc Mann Whitney tests for pairs of* ***occupational groups*** *with notable differences in* ***FRI*** *values.*

	Food Preparation & Serving-Related Occupations	**Sales & Related Occupations**	**Farming, Fishing, and Forestry Occupations**	**Production Occupations**	**"laborer"**
Construction & Extraction Occupations	p=.001	p=.008	p=.006	p=.043	p<.001

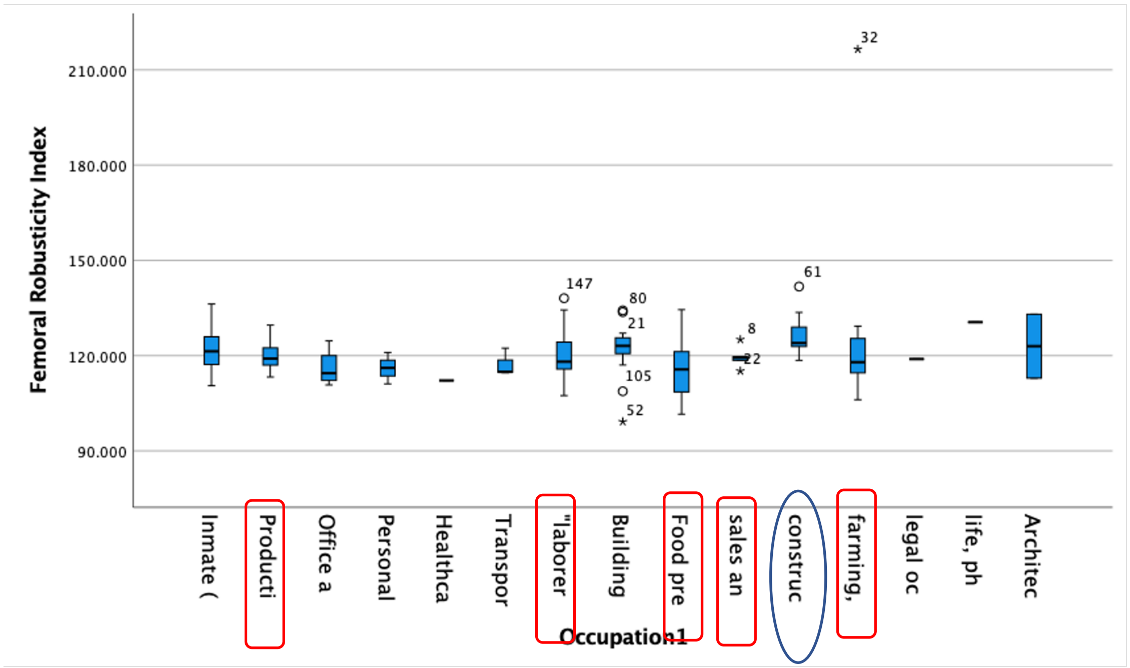


Figure 5.1. *Mean, range, and standard deviation of the 15 occupational categories (Scheme 1) included in this study. Occupations listed in red boxes are those with statistically different FRI from construction and extraction occupations as demonstrated in Table 5.12.*

The same statistical tests performed using Occupation Scheme 2 as the grouping variable indicate no significant difference in FRI (p=.078), FMS (p=.459), HRI (p=.240), or HMS (p=.945) between these aggregated categories. Since construction/extraction seems to be the only occupational group that is seriously different from the rest, it is highly likely that its inclusion into a larger category diluted its different and made it statistically undetectable.

Of the four robusticity measures, only one (FMS) was significantly correlated with age at death (p=.016). Statistical testing validated the existence of a linear relationship between the two variables, and thus linear regression was used to further investigate the nature of this relationship. Preliminary testing revealed three outliers that existed beyond three standard deviations from the norm and were subsequently omitted from regression testing. After filtering of outliers, the resulting regression equation (FMS= -.001*age at death + 1.037) was significant ($p=.027$) but explained less than 3% of variation in the dependent variable. The sign of the coefficient indicates that as age increases, FMS decreases. FMS is reflective of loading stress directionality. The generated regression equation demonstrates that, in the UISC sample, as an individual aged, their femoral diaphysis shape shifted from more circular towards more platymeric. The relationship expressed indicates that as individuals age, and in the case of this sample, transition into care or mental institutions, a prolonged tendency towards multidirectional movement begins to be replaced by unidirectional movement. This may possibly mean that elderly individuals are performing a less diverse array of tasks/labor. It is interesting, however, that FRI does not show a strong link to age at death, indicating that mobility is not significantly decreasing, but the directionality of related mechanical stress is.

Based on previous testing that suggested the significance of length of residency, robusticity measures were investigated for any association with this variable. There were no strong relationships between any robusticity measures and length of residency in the United States (Table 5.13). However, in the case of length of residency in CA and HRI, this correlation was deemed statistically significant at the $p<.05$ level. Linear regression testing revealed no outliers and a significant model, but length of residency in CA only explained approximately 5% of variance in HRI. Thus, although CA residency is a significant variable, it alone does not explain a majority of robusticity outcomes in the humerus.

Table 5.13. *Results of linear regression testing investigating associations between* ***robusticity*** *measures and* ***length of residency*** *in the United States and California.*

		HRI	HMS	FRI	FMS
Length of Residency in the U.S.	R^2	.000	.000	.000	.000
	F	.004	.972	.043	.001
	t	.065	-.986	.208	.035
	p	.948	.327	.835	.973
Length of Residency in California	R^2	.052	.007	.002	.001
	F	4.606	.628	.258	.081
	t	2.146	-.792	.508	-.284
	p	**.035***	.430	.612	.777

*Significant at the p<.05 level

The final portion of testing directly involves the two dependent variables of greatest interest to this dissertation: notch volume and NWI. Hierarchical linear regression was used to control for potential confounding "base" variables in Step 1 of the models, and each robusticity variable was added independently in Step 2 of each model. Recall from previous sections that the variables that show significant relationships with NWI and for which I must control are length of residency in CA, Occupation Scheme 2, and Birth Location Scheme 1. For notch volume, I control for these same three demographic variables in addition to stature and death cohort. Of the regression models computed, only the addition of HRI improves upon the control variable model at a statistically significant level (Table 5.14). The Step 2 regression model (includes "base" variables and HRI) explains approximately 46% of variance in intercondylar notch volume. Though other Step 2 regression models are significant, none of the robusticity variables add notable predictive power to any of those models for NWI or notch volume.

Table 5.14. *Hierarchical linear regression results from tests to determine whether the addition of* ***robusticity*** *variables improves the control variable model with respect to* ***NWI*** *and* ***notch volume****.*

		HRI	**HMS**	**FRI**	**FMS**
NWI	**Model R^2**	.089	.105	.126	.121
	Model Adj R^2	.037	.056	.090	.085
	R^2 Change	.012	.028	.000	.000
	F Change	.908	2.293	.024	.039
	p-value for F Change	.344	.134	.878	.844
	Model p	.158	.087	**.011**[a]	**.012**[b]
Notch Volume	**Model R^2**	.456	.388	.409	.394
	Model Adj R^2	.409	.337	.373	.357
	R^2 Change	.071	.014	.013	.004
	F Change	9.116	1.635	2.170	.722
	p-value for F Change	**.004**	.205	.144	.398
	Model p	**<.001**[c]	**<.001**[d]	**<.001**[e]	**<.001**[f]

[a]p-values for variables in regression model: length of residency in CA (**p=.003**), Occupation Scheme 2 (p=.935), Birth Location Scheme 1 (**p=.022**), FRI (p=.878).
[b]p-values for variables in regression model: length of residency in CA (**p=.003**), Occupation Scheme 2 (p=.958), Birth Location Scheme 1 (**p=.025**), FMS (p=.844).
[c]p-values for variables in regression model: length of residency in CA (p=.826), Occupation Scheme 2 (p=.708), Birth Location Scheme 1 (p=.544), stature (**p<.001**), death cohort (**p=.020**), HRI (**p=.004**).
[d]p-values for variables in regression model: length of residency in CA (p=.309), Occupation Scheme 2 (p=.672), Birth Location Scheme 1 (p=.356), stature (**p<.001**), death cohort (**p=.032**), HMS (p=.205).
[e]p-values for variables in regression model: length of residency in CA (**p=.007**), Occupation Scheme 2 (p=.115), Birth Location Scheme 1 (p=.092), stature (**p<.001**), death cohort (**p=.023**), FRI (p=.144).
[f]p-values for variables in regression model: length of residency in CA (**p=.007**), Occupation Scheme 2 (p=.259), Birth Location Scheme 1 (p=.062), stature (**p<.001**), death cohort (**p=.020**), FMS (p=.398).

To test whether any of the robusticity measures were related to notch stenosis (a binary variable), logistic regression was used. Potential confounding factors in this test are stature and sex, both proxies for body size. Previous testing indicated no sex-bias in robusticity measures, and there were also no significant correlations between HRI (p=.742), HMS (p=.263), FRI (p=.235), or FMS (p=.180) and stature, so neither of these variables needed to be controlled for. Binary logistic regression indicates that the robusticity measures are not significantly related to a stenotic notch (HRI: p=.685, HMS: p=.122, FRI: p=.735, FMS: p=.247). One caveat of this test is that only ten individuals met the clinical threshold for notch "stenosis," so the possibility of a relationship between robusticity measures and stenosis still exists, if unlikely.

Completing the notch volume and NWI portion of statistical testing with respect to robusticity measures are a series of directional asymmetry tests. Including only individuals with values for both the left and right femur, several paired-samples t-tests seeking patterns in midshaft robusticity and shape overall, and across birth cohorts, death cohorts, and occupations (scheme 2) were utilized. Overall, there was no directional asymmetry in NWI (p=.137), notch volume (p=.315), or FMS (p=.305), but significant asymmetry in FRI (p=.005). Further exploratory testing is conducted via the use of birth and death cohorts as selection variables. Birth cohort 6 was omitted due to its small sample size. Birth cohort 1 (1842-1852) indicated no directional asymmetry in NWI (p=.141), notch volume (p=.729), FMS (p=.515), or FRI (p=.534). This cohort is not the source of the significant result in the overall sample paired t-test. Birth cohort 2 (1853-1863) is also not the source of the significant directional asymmetry in the overall sample (NWI: p=.066, notch volume: p=.908, FMS: p=.200, FRI: p=.833). Birth cohort 3 (1864-1874) indicates the first significant result in this vein of testing with strong directional asymmetry in FMS (p=.016) and FRI (p=.009), while notch volume (p=.288) and NWI (p=.461) remain without a strong orientational pattern. Birth cohort 4 (1875-1885) illustrates the same trend as seen in cohort 3 with FMS (p=.043) and FRI (p=.005) possessing clear asymmetrical tendencies while notch volume (p=.451) and NWI (p=.506) continue to demonstrate relatively balanced values. Birth cohort 5 (1886-1896) is unique from those previous in that notch volume (p=.009) is the only measure to exhibit directional bias (NWI: p=.867, FMS: p=.983, FRI: p=.281). It is worth noting that this is the smallest of the included test cohorts and thus possesses lesser statistical power.

Death cohort 1 (1929-1939), like the earlier birth cohorts, exhibits no evidence of directional patterning in robusticity or size of the distal femur (notch volume: p=.565, NWI: p=.164, FMS: p=.704, FRI: p=.064). Paired samples t-tests for death cohort 2 (1940-1952) also show an absence of directional asymmetry in NWI (p=.601), notch volume (p=.348), and FMS (p=.128). However, FRI does show directional bias (p=.010). It is notable that in both birth cohort- and death cohort-related analysis, directional asymmetry only becomes apparent in the later portion of the time period. The interpretation of this finding will be discussed in the subsequent chapter.

Among occupational groupings (Scheme 2 used for larger group sizes), there is very little evidence for directional asymmetry overall (Table 5.15). There are two exceptions to this pattern. Notch volume is highly asymmetrical in occupational group 4 and FRI is asymmetrical in the "laborer" category. Group 4 occupations include: food preparation, production, and material moving positions. Production occupations include carpet weaver, shoemaker, painter, seamstress, newspaper printer, and horseshoer. The most common transportation occupations were ship-related jobs. Food preparation occupations primarily referred to chef, cook, and food server positions. All of these are fairly specialized occupations that would relegate much of the work to the dominant hand. From previous statistical testing, it is clear that notch volume is strongly related to HRI, a reflection of handedness. Handedness tends to be paralleled in footedness (e.g., Barut et al., 2007), with a large majority of people having a dominant foot that matches their dominant hand. While this would beg the question of why robusticity measures do not also show asymmetry, the previous results in this section clearly indicate that notch volume exists independently of femoral robusticity. Therefore, it is possible that the *type* of movement experienced by the knee influences the shape of the notch, leading to asymmetry at that locus, while the general mechanical loading stress remains relatively equal between the two limbs leaving FMS and FRI without a side bias.

Table 5.15. *Summary of p-values for **directional asymmetry** paired samples t-tests by groupings from **Occupation Scheme 2**.*

	Occupational categories included	**Notch Volume**	**NWI**	**FMS**	**FRI**
Group 1	*Inmate (in home)*	.928	.085	.717	.649
Group 2	*-Legal occupations* *-Life, physical, and social science occupations* *-Office and administrative support occupations*	.835	.206	.478	.079
Group 3	*-Sales and related occupations* *-Architecture and engineering occupations* *-Personal care and service occupations* *-Healthcare practitioners and technical occupations*	.491	.305	.239	.755
Group 4	*-Food preparation and food serving related occupations* *-Production occupations* *-Transport and material moving occupations*	<.001*	.056	.140	.184
Group 5	*-Building and grounds cleaning and maintenance occupations* *-Construction and extraction occupations* *-Farming, fishing, and forestry occupations*	.526	.748	.628	.381
Group 6	*"laborer"*	.345	.137	.234	.012*

*Significant at the .05 level

5.5 RESULTS PERTAINING TO HYPOTHESIS 3: GENETIC INFLUENCE

Before running any analyses on nonmetric traits and attempting to create groups that reflect relatedness patterns, a series of filters were used to select the most appropriate traits to use at this step. The filtering process is described in Chapter 4, Section 4.5 and the traits that made it through all layers of selection are listed in Table 4.4. As seen in Table 4.4, the traits of tibial squatting facet and talus squatting facet were not eliminated

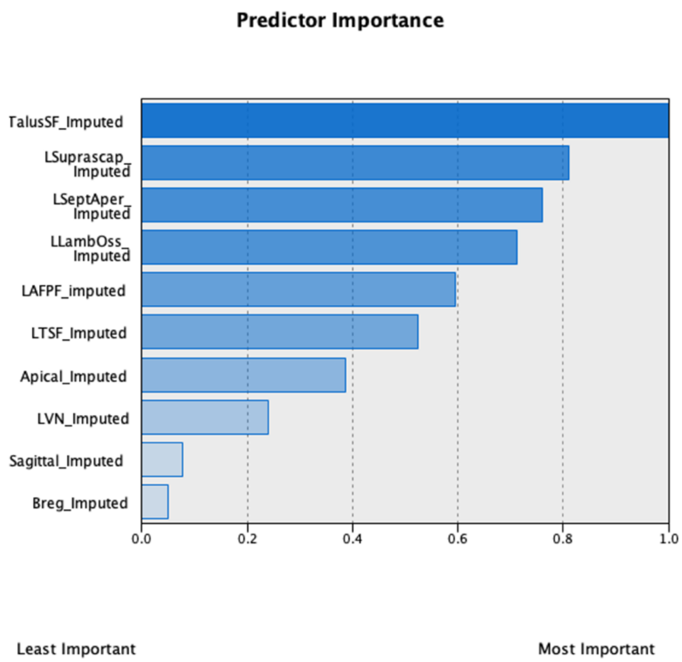
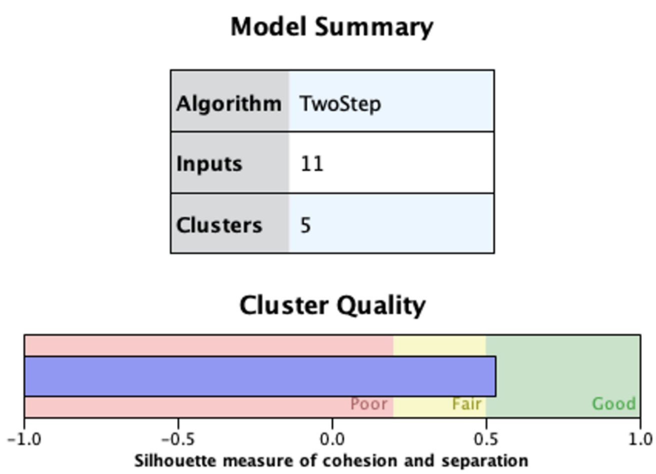


Figure 5.2. *Predictor importance assigned by 2-step cluster analysis in SPSS when squatting facets were included with the other nonmetric traits that passed through selection criteria.*

by any of the filter thresholds. According to Weiss (2017), fetal studies indicate that most of the biological potential to develop facets in a certain location is genetically determined. Consequently, Weiss states that it is "just as reasonable (or even more reasonable) to use these traits to understand biological distance as to understand activities" (2017: 129). However, due to the extreme importance of this trait as a predictor in original cluster analysis (Fig. 5.2), and out of an abundance of caution, both squatting facet traits were omitted from final nonmetric analyses. However, the decision of whether to include or omit "Allen's Fossa/Poirier's Facet" (AF/PF) is a more complicated one. Although the expression of AF/PF can be influenced by labor, movement, and cultural behaviors, it has been included in many biodistance studies due to its repeatedly demonstrated heritability component (e.g., Blom et al., 1998; Finnegan, 1978; Kennedy et al., 1993; Nyak et al., 2007). For these reasons, I have chosen to include AF/PF as a selection trait in cluster analysis.

2-step cluster analysis was used to categorize individuals into groups based on similarity in nonmetric trait expression. Unlike other clustering methods, 2-step cluster analysis does not require initial specification by the researcher of the number of clusters to generate. Instead, it chooses the number of clusters necessary by seeking a model that minimizes intragroup heterogeneity while maximizing intergroup differences. Most statistical methods for generating groups cannot handle missing data. To fix this, the mode was calculated for each of the 11 nonmetric traits and imputed for missing values. To prevent the introduction of unreliable data, individuals with more than 6 imputed values were omitted from subsequent cluster analyses.

Figure 5.3. *SPSS evaluation of the strength of cohesion and separation of the 5 clusters generated from 11 nonmetric trait inputs.*



For this sample, 2-step cluster analysis produced 5 clusters and a model that had intra- and inter-group distances that classified it as a "good" model (Fig. 5.3). According to historical documentation, four discrete "races" were extant in this sample, so I ran cluster analysis again, this time specifying that the maximum number of clusters to be specified by the model should be four. This parameter decreased the quality of the clusters into the "fair" category. This comparison suggests that historical assigned race does not map neatly to clusters based on epigenetic (nonmetric) variants and bolsters confidence in the 5-cluster model. The largest of the 5 clusters included 55 individuals, and the smallest 23 individuals. The nonmetric traits of the greatest predictive importance in this model were (in order from most to least important): vastus notch, lambdoidal ossicle, AF/PF, suprascapular notch, and apical bone.

The birth locations of the members within these five clusters are shown in Figures 5.4-5.8. I attempted to use statistical methods to ascertain whether nation of origin had any bearing on which cluster an individual was assigned, but the subgroups were too small to carry out reliable testing. Visual representation presented an alternate method by which the composition of these clusters might be understood. Due to the large group represented by the "Other" category in Birth Location Scheme 1, pie charts were produced using Birth Location Scheme 2 groupings. The intent behind seeking trends in cluster membership via nation of birth is to partially examine how well these clusters reflect ancestry and bolster the hypothesis that these groups are genetically similar due to a shared history.

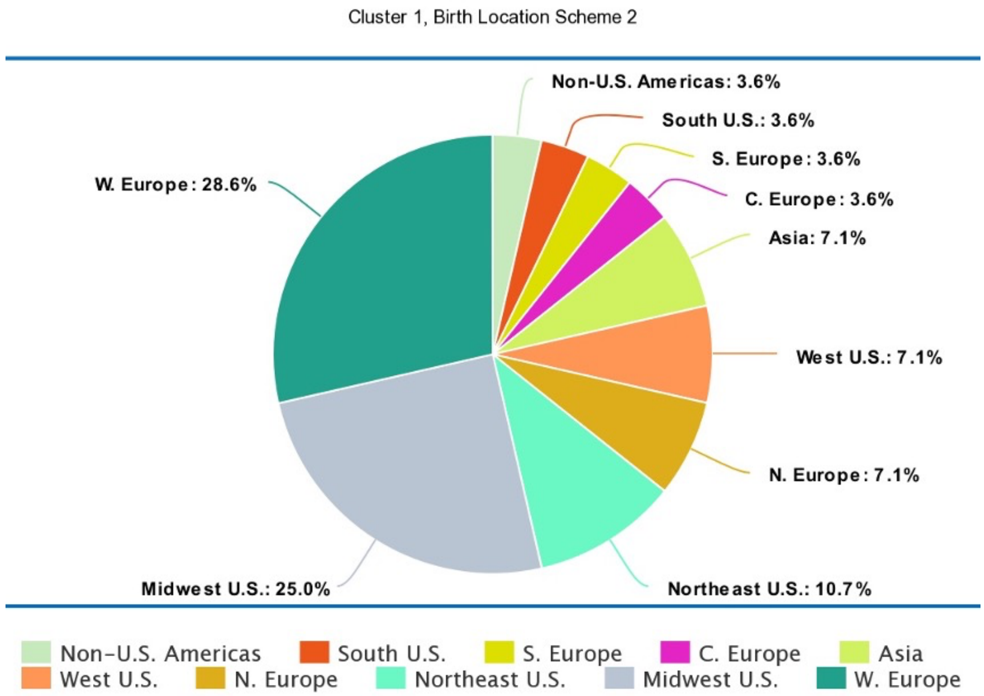


Figure 5.4 (Above). *Location of birth for individuals in Cluster 1.*

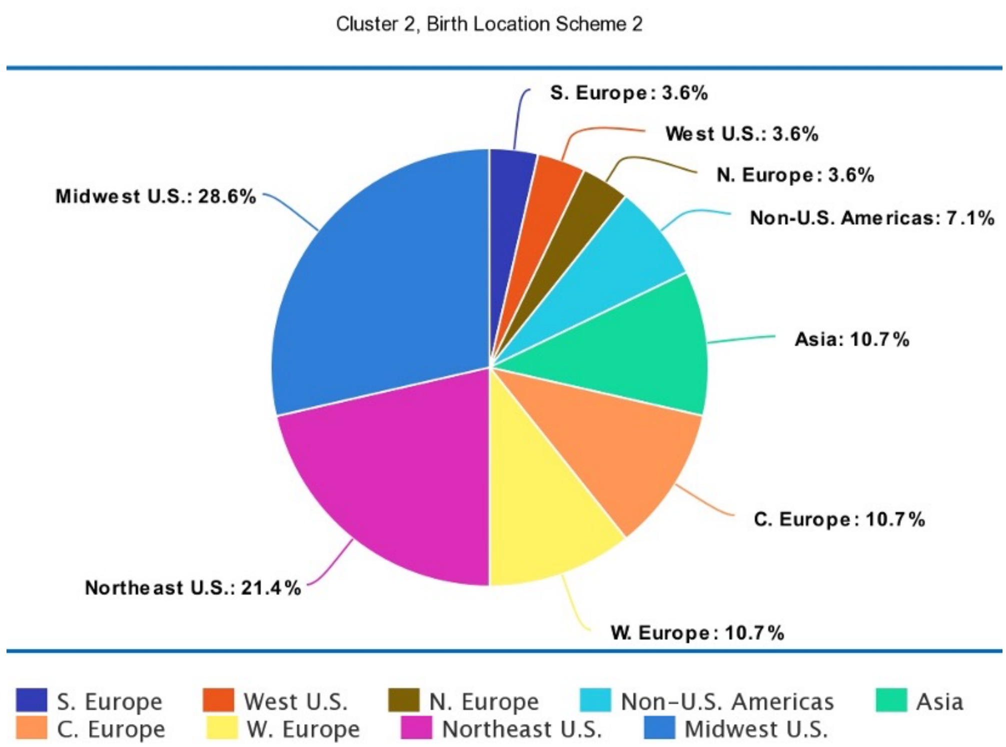


Figure 5.5 (Above). *Location of birth for individuals in Cluster 2.*

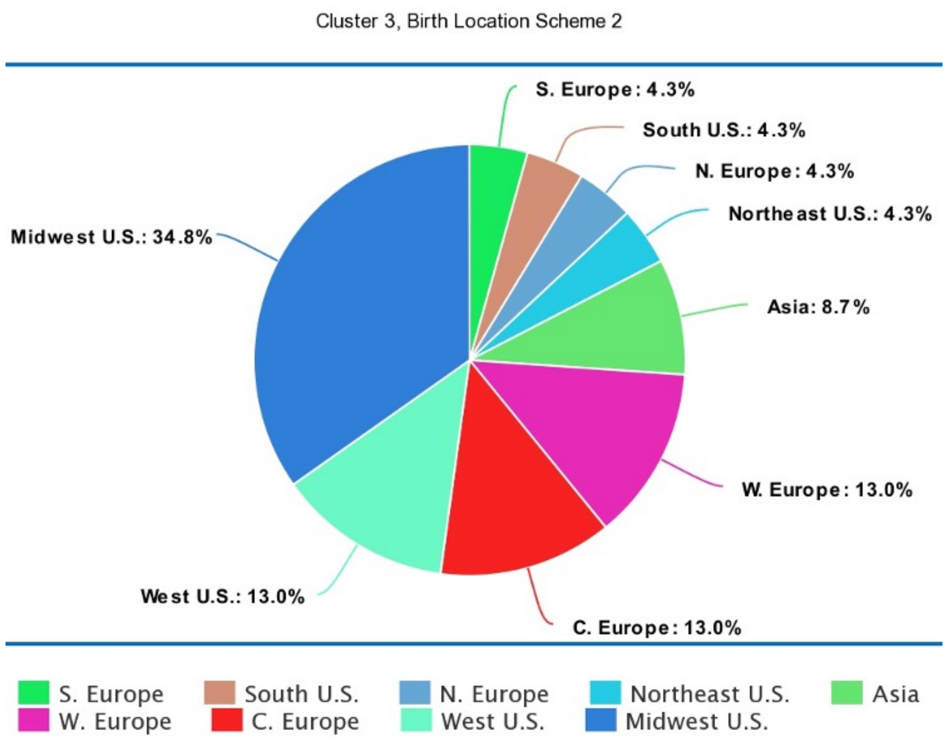


Figure 5.6 (Above). *Location of birth for individuals in Cluster 3.*

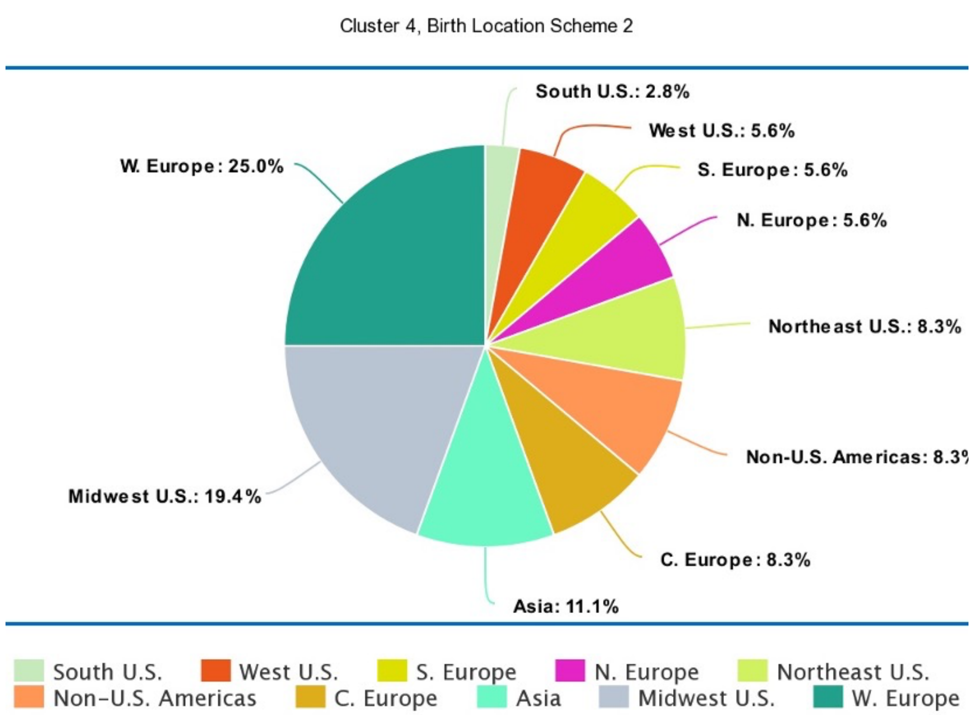


Figure 5.7 (Above). *Location of birth for individuals in Cluster 4.*

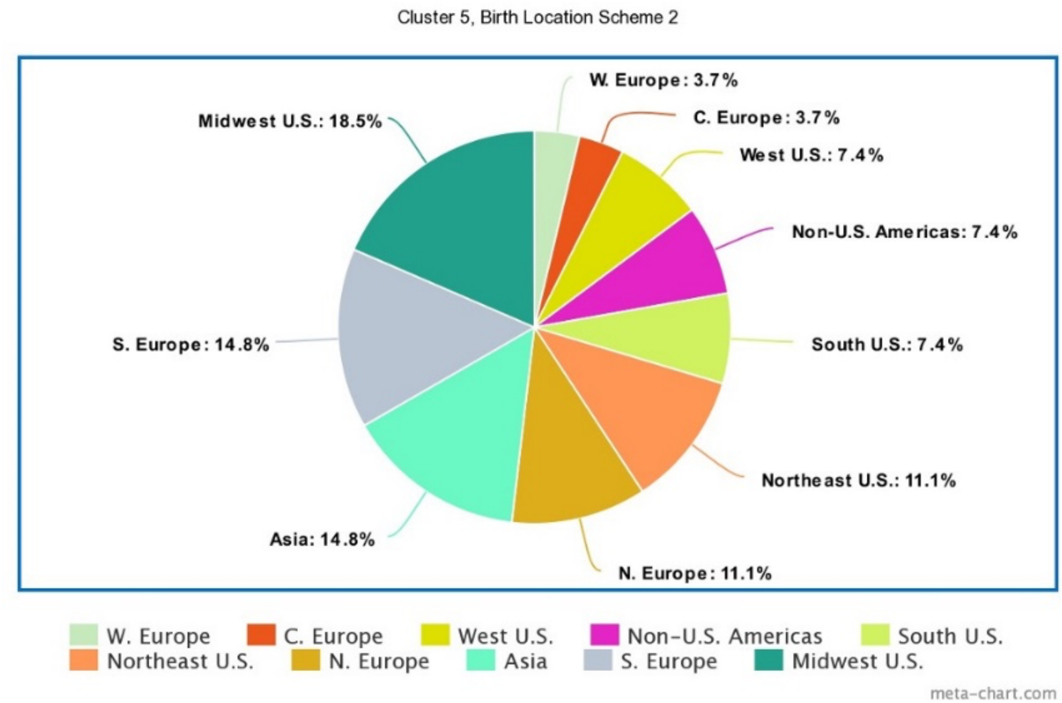


Figure 5.8. (Above). *Location of birth for individuals in Cluster 5.*

The results from these pie charts (Figs. 5.4-5.8) indicate anything but a clear answer on the ancestral origins of the five cluster groupings. However, we should not be quick to dismiss the utility of cluster groupings or their reliability at reflecting morphological similarity among members. Rather, I argue that these results indicate a limitation of the dataset itself, not the methods. Most individuals in the UISC subsample were born in the U.S. and this birth location does not properly reflect ancestry. For instance, someone of African descent characterized by a birth location in Tennessee does not properly represent ancestral heritage. While birth location for genetic parents was available for some individuals, it was not a common enough occurrence to inspire confidence in being able to move the focus back an additional generation. Furthermore, many parent birth locations were also in the U.S., which once again does not provide enough information to be a reliable ancestral proxy for the purposes of matching the nonmetric clusters with specific population groups.

To confirm that these clusters were meaningful groupings, and to partially test whether assigned racial categories reflect genetic similarity in any way, I used a series of Fisher's exact tests to investigate each nonmetric trait with respect to both assigned racial category and the generated clusters. It should be noted that only the assigned races of "white" and "Asian" were included in these tests, as the sample size for the other two racial groups was fewer than 5 individuals and thus too low to reliably include. The results (Table 5.16) indicate that zero nonmetric traits were a significant variable to either assigned racial category. Although the statistical power of this test is low due to the inclusion of only two racial groupings, it is suggestive of the fact that these historical racial categories are not a good reflection of genetics/ancestry, and that the cluster groups are a better representation of biological affinity and distance. Another Fisher's exact test seeks any statistical relationship between an individual's membership in assigned racial categories and the cluster group into which they are sorted. Results indicate no statistically meaningful association between assigned racial categories and the clusters generated from nonmetric data ($p=.900$). While more testing and a larger sample size are needed to lend more weight to this finding, multiple test results compellingly suggest that assigned racial categories are not an accurate reflection of genetic similarity (biological distance) and therefore cannot be used to test the impact of genetic factors on intercondylar notch volume. For the remainder of this section and subsequent testing, the five nonmetric trait-based clusters will be used as the grouping variable that represents genetic affinity.

Table 5.16. *Summary of Fisher exact testing to evaluate the significance of each **nonmetric trait** to assigned race and **cluster** groupings.*

Nonmetric Trait	Assigned Race p-value	Cluster Group (5) p-value
Metopic suture	1.00	.096
L coronal ossicle	1.00	.244
Bregma	1.00	.076
Sagittal ossicle	1.00	.013*
Apical	1.00	<.001**
L lambdoidal ossicle	.690	<.001**
L septal aperture	1.00	<.001**
L suprascapular foramen	.293	<.001**
L unfused acromial epiphysis	1.00	.755
L Allen's fossa/Poirier's Facet	1.00	<.001**
L vastus notch	.734	<.001**

*Significant at the p=.05 level
**Significant at the p=.01 level

With these new groups that are based on morphological similarities with proven heritability, it is worth the time to perform minor exploratory analysis to understand any potential interactions or notable relationships with previously investigated variables. I present now a summary of these results. Via one-way ANOVA testing, nonmetric cluster groups show no association with FMS (p=.419), FRI (p=.562), HMS (p=.414), or HRI (p=.819). Average stature also does not vary meaningfully between cluster groups (one-way ANOVA, p=.245).

Additional ANOVA testing indicates that length of residence in the U.S. (p=.560) and CA (p=.574) has no significant relationship with resulting nonmetric cluster group membership. These associations should be insignificant. If length of residency in either location was a significant variable in determining cluster group membership, then this would suggest that cluster groupings were not representative of genetic relatedness, but something else. Binary logistic regression results show an insignificant relationship between cluster group and presence of PH (p=.481, Nagelkerke R^2=.043) and an even weaker relationship to PR presence (p=.743, Nagelkerke R^2=.019). Based on one-way ANOVA results, cluster groupings have no bearing on NWI (p=.994) or notch volume (p=.387). These results are validated by linear regression (NWI: p=.718, notch volume: p=.527).

These outcomes are perhaps the most important of this entire dissertation. They demonstrate that, despite clinical literature operating from a perspective that assumes genetics are the primary determining factor for notch volume, biological contributions seem to have very little bearing on notch morphology. The effects of metabolic stress and labor greatly outweigh those related to genetics and ancestry.

5.6 OVERLAPPING INFLUENCE: INTERACTION BETWEEN THE HYPOTHESES

Throughout this chapter, I have tested numerous variable relationships under the umbrella of each hypothesis. In this section, I take all the variables of note and work to construct a strong model that explains as much variance in notch volume and NWI as possible. To briefly summarize, the variables that are statistically related to notch volume are: length of residence in CA, HRI, stature, death cohort, Birth Location Scheme 1, Occupation Scheme 2, and porotic hyperostosis. The scalar variables were centered using an SPSS function to make them more comparable to one another when computing interaction terms. It is not necessary to center categorical variables, so these were not altered. The SPSS compute function was used to calculate every possible interaction term within this variable pool. Multiple regression was run with all individual variables and their interaction terms. The results were first refined by addressing multicollinearity issues between variables. To identify a multicollinearity issue large enough to disrupt the reliability of results, the generated table of variance inflation factors (VIF) must be examined. If all VIF values are below ten, then there are no large multicollinearity issues (Regorz, 2020). However, when including interaction terms *and* their independent variable components in the regression model, it is unlikely for there to be an absence of problematic VIF values. In this case, there were several surpassing the threshold value of ten. At this point, another value called the condition index is examined. In the collinearity diagnostic table generated by SPSS, lines that have a condition index value above 15 are examined for variables that have variance proportion values greater than .80 (Regorz, 2020). If two variables in the same line show high variance proportions, then the multicollinearity problem is between this pair.

The sheer number of variables and their interaction terms included in this “kitchen sink” multiple regression model (Table 5.17), in addition to high incidence of multicollinearity, creates a kind of statistical “noise” that can mask some significant variables. The process of resolving multicollinearity issues reveals these hidden relationships. The final filtered, strong model is shown in Table 5.18. In this refined model, all variables and interaction terms shown are strongly related to notch volume, with most p-values well below .05. Although the R^2 value is higher in the unrefined model (which should indicate greater explanatory power of variance in notch volume), R^2

values increase with each variable added. The adjusted R^2 model does not experience the same effect, however, as it is a more conservative measure. Thus, a strong model has a similar R^2 and adjusted R^2, as seen in Table 5.18.

Table 5.17. *"Kitchen sink" regression model values with all potential interaction terms included as well as "base" variables.*

	B	Std. Error	ß	t	p	VIF
Constant	-65964.677	76380.30		-.864	.394	
Length of Residence, CA (CA)	44.974	142.989	.223	.315	.755	90.574
Occupation Scheme 2 (Occ2)	-906.584	988.081	-.367	-.918	.366	28.942
Birth Location Scheme 1 (BL1)	121.133	497.851	.116	.243	.809	41.183
HRI	188.026	347.353	.296	.541	.592	53.836
Death Cohort (YOD)	-3274.262	6211.449	-.310	-.527	.602	62.630
Porotic Hyperostosis (PH)	-10284.808	6002.908	-1.078	-1.713	.097	71.481
Stature	413.847	451.705	.777	.916	.367	129.770
*Interaction: CA*Stature*	-5.295	4.649	-.174	-1.139	.263	4.193
*Interaction: CA*HRI*	13.873	4.049	.360	3.426	**.002**	1.998
*Interaction: Stature*HRI*	8.731	11.349	.110	.769	.448	3.673
*Interaction: HRI*YOD*	-617.728	209.942	-1.267	-2.942	**.006**	33.464
*Interaction: HRI*BL1*	10.311	17.870	.115	.577	.568	7.180
*Interaction: HRI*Occ2*	62.576	56.456	.471	1.108	.276	32.625
*Interaction: HRI*PH*	-294.125	279.067	-.257	-1.054	.300	10.745
*Interaction: CA*PH*	90.574	63.059	.193	1.436	.161	3.244
*Interaction: CA*BL1*	-12.615	6.536	-.376	-1.930	.063	6.840
*Interaction: CA*Occ2*	2.327	16.137	.053	.144	.886	24.601
*Interaction: CA*YOD*	-50.291	107.533	-.274	-.468	.643	61.845
*Interaction: Stature*YOD*	259.664	273.695	.616	.949	.350	76.219
*Interaction: Stature*Occ2*	-35.321	45.802	-.315	-.771	.446	30.115
*Interaction: Stature*BL1*	-31.118	20.401	-.292	-1.525	.137	6.609
*Interaction: Stature*PH*	-138.060	230.935	-.120	-.598	.554	7.272
*Interaction: PH*Occ2*	3108.237	1336.835	1.594	2.325	**.027**	84.918
*Interaction: PH*BL1*	-449.215	619.423	-.292	-.725	.474	29.278
*Interaction: PH*YOD*	935.461	3033.791	.120	.308	.760	27.431
*Interaction: Occ2*BL1*	-54.860	71.150	-.287	-.771	.447	25.094
*Interaction: Occ2*YOD*	259.332	875.433	.163	.296	.769	54.549
*Interaction: YOD*BL1*	50.688	378.467	.068	.134	.894	46.173

R^2 =.828, adjusted R^2 =.673, model significance p<.001

Table 5.18. *Refined regression model after resolving multicollinearity issues amongst interaction terms and "base" variables.*

	B	Std. Error	ß	t	p	VIF
Constant	17846.881	937.924		19.028	**<.001**	
Occupation Scheme 2	-482.961	206.365	-.196	-2.340	**.023**	1.061
Stature	370.498	44.250	.695	8.373	**<.001**	1.047
*Interaction: CA*HRI*	9.831	3.235	.255	3.039	**.004**	1.072
*Interaction: PH*Occ2*	617.659	161.408	.317	3.827	**<.001**	1.040
*Interaction: HRI*YOD*	-187.762	40.754	-.385	-4.607	**<.001**	1.060

R^2=.644, adjusted R^2=.611, model significance p<.001

The final regression equation built from the refined model is: Notch Volume (mm^3) = 17846.881 - 482.961*Occ2 + 370.498*Stature + 9.831*(CA*HRI) + 617.659*(PH*Occ2) -187.762*(HRI*YOD). The coefficients in the equation indicate directionality of relationships. For instance, occupation is inversely related to notch volume. The categories in Occupation Scheme 2 are arranged ordinally, theoretically from the least to most labor intensive. The directionality of this relationship suggests that the greater the labor intensity of an individual's occupation, the smaller the notch size. Additionally, there is a positive relationship between stature and notch size, confirming that notch volume is partially a reflection of body size. In fact, from the standardized coefficient values (ß), stature has the largest influence on resulting notch volume (Table 5.18). The positive coefficient for the interaction term of length of residence in CA*HRI indicates that as either of those values increase, so too does notch volume. Additionally, simultaneous increase in both has a compounded positive effect of notch volume. The second interaction term (PH*Occ2) is interpreted a bit differently. If PH is absent, this term zeros out and does not impact notch volume. However, if PH is present, it increases notch size, and if the Occ2 category is higher, this effect is compounded. As heavier occupation on its own decreases notch volume, as evidenced by its negative coefficient in the regression equation, its presence in the positive interaction term with PH may suggest that those strong/healthy enough to survive metabolic stress have some protection against notch narrowing. This will be unpacked more in the following chapter. The final interaction term in the regression equation can be interpreted as HRI determining the strength of effect from the death cohort. When HRI is sub-1, then it reduces the effect of the death cohort, whereas an HRI greater than 1 enhances the effect of death cohort. In either case, these values have a positive relationship with notch volume, where an increase in either value is reflected by an increase in notch volume.

5.7 CONCLUSION

Hypothesis 1 asks whether experiences of metabolic stress may influence notch volume. Statistical results indicate moderate support for this hypothesis, as presence/absence of porotic hyperostosis has a strong relationship with notch volume. While I did hypothesize that metabolic stress would have an impact on notch morphology, the actual nature of this relationship was not quite what I expected. The presence of porotic hyperostosis is linked to larger notch size, not a more restricted space. As evidenced by the coefficient of the interaction term PH*Occ2 in the final regression model coefficients (Table 5.18), porotic hyperostosis matters less on its own than when it occurs with a high labor intensity occupation.

Hypothesis 2 seeks to establish whether high mechanical loading might impact notch volume. This hypothesis is relatively unsupported, but that does not mean that long bone robusticity is devoid of a link to notch volume. HRI, not either femoral measure of robusticity, is the variable with the strongest association to notch volume. Higher HRI is associated with greater intercondylar notch volume. The fact that notch space is not tied to FRI or FMS suggests that notch volume is not representative of mechanical stress on the lower limb. Rather, it seems to be more reflective of the type/range of movements performed, rather than the level of mobility required or loading frequency/degree of the femora. HRI's interaction with historical context – in the form of length of residence in CA and death cohort – is important to qualifying its effects on notch volume.

Hypothesis 3 tests one of the primary assumptions of medical studies of the intercondylar notch: that notch size is primarily determined by genetic ancestry. This hypothesis is not supported at all. Not only do assigned racial categories seem to have no meaningful relationship to genetic clustering of morphologically similar groups, but there also was no significant association between nonmetric (epigenetic) clusters and notch volume. While this sample size is small and further testing is necessary to confirm these findings, the results of this dissertation directly contradict previous biomedical opinions on the risk factors for notch stenosis.

The most important results and their implications are discussed and further contextualized with respect to this population and time period in the following chapter.

Chapter 6: Discussion of Results, Whiteness in Santa Clara Valley, and Research Limitations

6.1 INTRODUCTION

The central goal of this dissertation is to test three specific hypotheses about intercondylar notch (fossa) volume. In the process of investigation, important trends and findings do emerge outside of the scope of these three hypotheses. This chapter will discuss and recapitulate these significant results. Although intercondylar notch volume was the primary variable of concern in this research project, NWI will be discussed in several places for two reasons. First, I intend for this research to be comparable to medical literature. Even if this dissertation had not yielded any significant results, I wanted it at the very least to capable of aggregation into metanalyses of intercondylar notch quantification. This is a sample from a limited geographic and temporal scope that can offer a comparison to existing studies of modern populations. Second, I needed a methodological comparison to test whether NWI and notch volume are redundant measures. To draw a conclusion on this point, I had to run the same statistical tests with both measures and contrast the results. I do not employ the use of NWI to validate it as an accurate characterization of notch morphology. Similarly, the use of assigned racial categories in some places should not be taken as acceptance of their genetic validity. The meaningfulness of this identity category must assessed due to the frequency with which race is used as a proxy for group affinity in academic studies across disciplines. Thus, while this chapter will summarize the most important findings, contextualize them, and discuss their implications for current and future research directions, it also intends to address controversial claims and ethical conundrums.

6.2 "BASE" VARIABLES AND THE UISC

"Base" variables, as I refer to them in this dissertation, refer to the variables collated from documentation that describe the UISC population and whose relationship to notch volume and NWI needed to be tested. This section summarizes the range of "base" variables examined and presence/absence of meaningful associations with notch volume or NWI.

The human species is known to express some degree of sexual dimorphism. Typically, males are larger and more robust than females. Consequently, NWI and intercondylar notch volume were investigated with respect to sex. The former has no relationship while the latter has a significant one. The same pattern is evident with respect to stature. The reason for this difference is that NWI is a ratio in which two linear measurements (with the same units) are divided by one another. The result is a unitless index that inherently controls for body size. On the other hand, notch volume is a cubic measure, and even if it were to be divided by a linear measurement, it would still not be a true index as it would not be unitless. One dimension of measure would remain, and therefore it would still be subject to influence by body size. Thus, body size must be controlled for with respect to notch volume to detect other significant variable associations. One potential fix for this issue is to use 3D scanning technology to find the volume of the entire femur. This could then be converted into a ratio of notch volume/femoral volume, or a true index. The challenge of this solution is that it requires the femur be intact, and preservation of this level is rare in many contexts.

There is some concern in the literature (e.g., Hirtler et al., 2015), that notch parameters narrow throughout the aging process. In this sample, neither notch volume nor NWI are impacted by age at death. Age at death is negatively correlated with notch width (the numerator of NWI), but not at a statistically significant level ($p=.468$). This result suggests that trends in notch width, and subsequently notch volume, are behaviorally dependent. Notch width is a dimension of both NWI and notch volume, and as such, will affect both measures though they are not identical. As will be discussed in more depth in a later section, though there is a lack of a relationship to age, there are relationships to experiences of metabolic and labor stress which vary by culture, socioeconomic status, and perceived race. In this particular sample, though, narrowing of the notch with age is not a possible confounding trend.

Length of residence in California, but not the U.S., is significant to both NWI and notch volume. The length of an individual's residence in the state is on average about 20 years shorter than the length of time spent in the country overall. The statistical distinction between the experiences of time in the U.S. overall and experiences in California, based on patterns seen in HRI and discussed later, reflects that there is something unique about labor patterns in the Santa Clara Valley. The Valley achieved distinction in the global market for its supply of produce from farms, horticulturalists, and extensive orchards. The fertile nature of the Santa Clara Valley opened up a huge occupational sphere where people could be involved with food on many levels, including planting, growing, harvesting, transporting, selling, and cooking. Even people in Californian almshouses and mental institutions could be involved in the production of their own food, including harvesting and selling some of it for their own profit (e.g., City and County of San Francisco). This production specialization may be the reason why relocation to California generated unique labor patterns mirrored by osteological changes.

Race, perhaps surprisingly, was not meaningful to either NWI or notch volume. The relationship between postmortem assigned race and actual genetic makeup is examined and discussed further in section 6.8, but as a "base variable," the racial category assigned to an individual had no bearing on osteological outcomes at the distal femur. Thus, race is ignored in a majority of statistical testing for the first two hypotheses but is considered in-depth with regard to the third hypothesis.

Lived experiences in different time periods are considered through the use of birth and death cohorts. Birth cohorts are spread across approximately 70 years, while death cohorts only span about 20 years. For both variables, cohorts themselves are divided into roughly decades. In the original conception of these variables, the only difference between the two was assumed to be scale. Put another way, death cohorts are more aggregated, while birth cohorts are more stratified, so they were perceived as altered scales of looking at the same lived experiences. However, results indicating lack of a significant association between an individual's birth and death cohort suggests that these variables may be more distinct than previously considered. A lack of notable correlation between them demonstrates that persons born during the same decade are not tending to perish at the same time. Moreover, birth cohort is not meaningful to NWI or notch volume, but death cohort is significant to the latter. Distinct patterns of association to other variables, in conjunction with a lack of correlation between birth and death cohort variables, further implies that scale is not the root of divergence here. Rather, these variables likely reflect particular segments of the life course. Individuals of the same birth cohort lived in a similar historical sociocultural context during early life, while individuals in the same death cohort experienced similar contexts later in life. The separation between the two variables, then, is less about size of the groupings and more about portion of the lifespan in focus. Despite its lack of a statistically significant relationship to NWI and notch volume, birth cohort is not dropped in the analysis because it is still a useful tool for looking at smaller groups of individuals born during a particular period.

Occupational category is also divided into two schemes. Occupation Scheme 1 is comprised of nominal categories as defined by the Bureau of Labor and is highly stratified. Occupation Scheme 2, in contrast, represents ordinal, aggregated categories ranked in order of increasing labor intensity. These variables are redundant in looking at the same demographic factor – labor type – but examine it in two distinct manners. Their redundancy is supported through results demonstrating that both are independently related to notch volume, and neither to NWI (Table 5.1). Throughout the statistical analysis, I oscillate between the two measures depending on the nature of the question being asked. In some instances, more precise categories are needed, while in others, a larger generalization suffices, or ordinal data are needed.

Birth location schemes are represented in much the same way as occupation and birth/death cohorts. Birth Location Scheme 1 divides birth locations by the most commonly listed countries but leaves a large "Other" category of miscellaneous countries listed only once. Scheme 2 groups birth locations by continental regions, which is helpful for seeing large trends, but flattens out country-related differences. Birth Location Scheme 1 is significant to both NWI and notch volume, but Scheme 2 is only strongly related to notch volume (Table 5.2). As discussed in the previous paragraphs, the choice of which level of this variable to employ in statistical analysis is reliant on the dependent variable and the scale necessary for the research question being asked. It is also dependent on sample sizes within each category, as preservation of certain elements may make groups more or less populous, and thereby strengthen/weaken the statistical power of the tests utilizing that variable.

Finally, there is no evidence that cause of death has any relationship to notch volume or NWI. Most of the individuals in the UISC perished as a result of cardiovascular disease, followed by mortality from parasites and infection. While this might be interpreted as a narrow notch not being linked to immunological stress, parasitic infestation and infection are acute conditions that likely would not have time to notably impact the intercondylar notch volume. In contrast, cardiovascular disease is more of a chronic condition and therefore I can more reliably argue that a small intercondylar notch is not a biological response to stress on the cardiovascular system. Although more research is necessary to confirm this finding, results do suggest that intercondylar notch volume is not influenced specifically by immune burden.

The variables discussed in this section indicate the relationships that must be considered throughout the course of statistical testing. For example, I cannot test the relationship between notch volume and long bone robusticity without first testing if stature is a confounding variable with respect to this relationship. If so, then the covariance must be controlled. Understanding whether "base" variables are significant covariates is crucial to constructing reliable tests and interpreting the results. This initial exploratory testing laid the groundwork for designing the statistical tests for the three primary, and any auxiliary, hypotheses in this dissertation. The following discussion of results is based on tests that incorporated these initial results and contributed to the lens through which broader interpretations are made.

6.3 ARE NWI AND NOTCH VOLUME REDUNDANT MEASURES?

This question can be answered purely from the results presented in Section 5.2 but strengthened through the findings in subsequent testing. If NWI and notch volume are different measures of the same aspect of the distal femur, then they should have similar relationships with the array of variables tested. With respect to the "base" variables, notch volume had a significant association with stature, while NWI did not. However, this difference is not as meaningful as it might appear. NWI is a ratio between bicondylar width and notch width. Considering this as a mathematical equation, the numerator and denominator are both presented (typically) in the unit of millimeters. The act of dividing two numbers with the same unit cancels out the units entirely and leaves behind a unitless representation, an index. In other words, NWI should be free from dependence on body size. Some researchers have expressed a concern that NWI does not entirely control for body size, as previous results suggest that bicondylar width increases with height while notch width does not (e.g., Shelbourne et al., 1998). Within the scope of this particular study, though, NWI demonstrated no significant relationship with stature (i.e., height) and does seem to adequately control for body size.

Notch volume, however, is not inherently standardized by body size. Even if I were to create a ratio where notch volume was expressed (divided) by relationship to stature, the units are not identical. Notch volume is measured in cubic millimeters while stature is not measured in a cubic unit. The result is that the ratio between notch volume and stature would continue to carry units that are related to body size in the other two dimensions (i.e., $mm^3/mm = mm^2$). Framed another way, volume encapsulates length, width, and height; standardizing this ratio by stature only controls for one of these dimensions (height) and does not result in a unitless index. Width and length dimensions of the notch would still be a product of stature to some degree. The importance of this discussion of units and indices is that because notch volume and NWI are quantified differently, we expect to see the former related to body size while the latter is not. Therefore, the fact that only notch volume is strongly related to stature neither confirms nor negates the argument that notch volume and NWI represent different characteristics of the intercondylar notch. Similarly, notch volume demonstrated a significant relationship with sex, while NWI did not. Due to sexual dimorphism in our species, sex as a variable does seem to relatively consistently reflect body size and as such also does little to answer the question posed in the section header.

In some cases, NWI and notch volume do exhibit the same pattern of variable relationships. For instance, neither are related to age at death, length of residence in the United States, birth cohort, cause of death, periosteal reaction, caries frequency, humeral midshaft shape, femoral robusticity index, femoral midshaft shape, or nonmetric clusters. On the other hand, both are strongly associated with length of residence in California and Birth Location Scheme 1. However, this is where the similarities end. Notch volume alone has a significant relationship with Birth Location Scheme 2, death cohort, both occupational schemes, PH, and HRI. The null hypothesis being tested here is that NWI and notch volume are measures of the same aspect of the intercondylar notch, with the only difference being that NWI inherently controls for body size. Given the divergences in the relationships between these measures and a number of variables, it is possible to reject the null hypothesis that NWI and notch volume are redundant variables.

As discussed earlier, it is important to consider whether the variables examined have an association with body size. If this is the case, then NWI and notch volume should demonstrate different types of relationships with the variables of note. However, if they do not, then these discrepancies become meaningful. For example, there is no reason that death cohort should be dependent on body size. So, according to the null hypothesis, both NWI and notch volume should either both be related or both unrelated to death cohort. From the results section and the summary given above, it is evident that notch volume does have a significant relationship with death cohort, while NWI does not. This pattern is seen in several variables with no dependency on body size, leading to the conclusion that NWI and notch volume are in fact not redundant measures.

The distinction between the two is that NWI is only concerned with a unilateral measurement: width. Notch volume incorporates width, depth, and height simultaneously for a more accurate representation of the space in which the ligaments and tendons of the distal femur exist. Given the relatively affordable and accessible nature of photogrammetry tools, such as the app Polycam, and the free access of 3D mesh manipulation programs, such as Meshmixer, for university-affiliated individuals, it is worth the extra time and effort to use notch volume when conducting research involving the femoral intercondylar notch.

6.4 IMPORTANT METABOLIC STRESS PATTERNS IN THE UISC SUBSAMPLE

The null hypothesis pertaining to this section is that metabolic stress, reflecting nutritional deficiencies and infection load, has no relationship with intercondylar notch volume. This was perhaps the most difficult hypothesis to test as preservation issues notably limited the number of individuals able to be included in the statistical analyses. For instance, documentation of cribra orbitalia necessitates at least one orbit be generally well-preserved. For the documented portion of the UISC, if any part of the cranium was present, it was most commonly the calotte. Orbits were rarely preserved, and a similar dearth of dental elements also presented a challenge to assessing caries and enamel hypoplasia frequencies.

In the UISC sample discussed here, 48 out of 186 individuals possessed teeth with enough crown present to document caries presence. 139 caries were noted on the total 378 preserved teeth, resulting in an average of .37 carious lesions per tooth. Of the 378 teeth, 107 were afflicted with at least one carious lesion (28.3%). 40 out of the 48 individuals, or approximately 83%, were affected by a carious lesion. To contextualize this number as high, low, or as expected, I make comparisons to other contemporaneous populations. The sample most similar to the UISC is that associated with the cemetery for the Santa Clara Valley Medical Center (SCVMC) in the late 19th century. Among these individuals who were from the lowest socioeconomic echelon, like those in the UISC, 80.8% of the individuals in the sample had at least one carious lesion and 15% of all teeth were affected (Rodrigues, 2016). Buzon and colleagues (2005) examine another similar group who were interred at the Legion of Honor Cemetery. Individuals buried at the Legion of Honor Cemetery died in the latter half of the 19th century in San Francisco. This cemetery, like the UISC and SCVMC samples, was primarily comprised of the poor and indigent, in addition to smallpox victims and people of Chinese ancestry (Buzon et al., 2005). Middle class and affluent individuals chose to be buried in private cemeteries rather than these Potter's Field aggregated plots whenever possible and are therefore greatly underrepresented. In the Legion of Honor Cemetery population, 43% of individuals and 8% of total teeth presented at least one carious lesion (Buzon et al., 2005). These numbers are lower than those seen in the UISC subsample, with 83% of individuals and 28.3% of total teeth affected.

Other relevant contemporaneous, low socioeconomic status burial grounds include: (1) Belleville, a cemetery associated with St. Thomas Anglican Church in Ontario, Canada used from 1872 through the early 1900s, (2) Salt Lake Valley Cemetery, a Mormon pioneer population in Utah from the 19th century, and (3) Highland Park, a 19th-century cemetery used primarily for decedents from a nearby almshouse in Rochester, New York. Caries frequency rates, reported in percent of teeth with at least one lesion, was 31% for Belleville (Saunders et al., 1997), 32.2% for Salt Lake Valley (Tigner-Wise, 1989), and 31.7% for Highland Park (Higgins et al., 2002; Sutter, 1995). When comparing the UISC to these sample populations, the UISC is generally equivalent in percentage of teeth and individuals affected, with the exception of the Legion of Honor Cemetery population. This population has lower statistics for both categories.

Given that decreases in socioeconomic status are strongly associated with increases in the sugar content of one's diet (Rahal et al., 2023), which in turn is a primary cause of caries development (WHO, 2017), caries frequency for the UISC suggests that this sample may have experienced similar nutritional restrictions as comparative populations. Other potential causes of generally high prevalence of caries in low socioeconomic status groups include diets heavier in carbohydrates like maize (e.g., Schollmeyer and Turner, 2004) and length of lifespan, which may reflect time to accrue caries and overall greater enamel wear. However, due to the use of the UISC as an anatomical teaching collection, evident by clear practice of dissection methods, it is worth noting that there may be an issue with preservation bias with respect to dental elements. Nonetheless, it is likely that the individuals in the UISC had a diet of similar cariogenic level to other contemporaneous destitute populations in industrial locations.

Of the 186 individuals in the UISC subsample, 39 individuals had teeth with enough preserved buccal surface to score for LEH and 27 (69.2%) presented with at least one instance of hypoplasia. This should be considered a conservative estimate as LEH was scored with the naked eye and fainter enamel disturbances might not be visible without a magnifying aid. The Legion of Honor Cemetery sample had an LEH prevalence of 50% (Buzon et al., 2005). In the Monroe County Poorhouse Cemetery population of Rochester, New York (in use from 1826-1863), approximately 70% of individuals presented with at least one clear instance of LEH (Lanphear, 1990). The Milwaukee County Institutional Grounds Cemetery (in use 1882-1925) has a notably lower LEH presence of 58.6% (Polli, 1997). A subsample of the Terry Collection, representing individuals who died in St. Louis with birth years between 1837-1943, had an even lower overall LEH frequency of 33.9% (Zarenko, 2014). However, the Terry Collection did have a significant racial skew, with the African American sample expressing over twice the rate of LEH (55.4%) as Euro-American individuals (12.5%).

Compared to samples of the same time period and of the same socioeconomic makeup as the UISC, the sample in this study did exhibit a high proportion of individuals with at least one instance of LEH, though not extreme enough to be considered anomalous. However, at this point a discussion of hidden heterogeneity and the osteological paradox is necessitated (Wood et al., 1992). LEH can only form if the person survives the stressor. Since there are no children in the UISC and a dearth of them in the contemporaneous samples referenced, we are seeing a sample of people who survived into adulthood, some of whom experienced strong enough stressors in early life to develop LEH. Yet, we cannot know how many experienced similar stressors and did *not* survive. Therefore, while the high prevalence of LEH within UISC individuals may suggest higher frequencies of physiological insults that interrupted growth compared to other poorhouse/institutionalized populations, it may also mean that UISC individuals were healthy enough to recover from these insults (i.e., were not frail).

In regard to PR, no distinction was made between active and healing lesions due to recognizably low interobserver agreement on this aspect (e.g., Biehler-Gomez et al., 2020). Identifying the stage of the lesion could aid in speaking to the frailty or lack thereof within the UISC (i.e., high prevalence of active lesions points towards high frailty), but also misidentification in this relatively small sample size could greatly skew interpretations. General prevalence of tibial periosteal reactions for UISC individuals was 17.7%, similar to the rate of 21% seen in the Legion of Honor Cemetery (Buzon et al., 2005). The Terry Collection subsample mentioned earlier cites a prevalence of 30.4% for African and Euro-Americans combined (Zarenko, 2014). A larger study of the Terry Collection reports an even higher 69.5% of individuals with periosteal reactions (Gengo, 2014). The New York African Burial Ground final report (Null et al., 2009) also lists a high periosteal reaction prevalence of 55.9%. In this particular comparison, the UISC sample referenced for this dissertation is on the low end of reported ranges from largely contemporaneous populations. Although most periosteal reactions seem to be attributed to infection or disease burden, this pathology can also be the result of trauma, overlying ulcers, and nonspecific stress incidents (Roberts, 2019). So, the lower rates of PR in UISC individuals do not necessarily indicate a diminished infection burden but could be generalized to infer less overall biological stress experienced. It is also possible that UISC individuals were more frail than similar populations and did not develop periosteal lesions prior to death, but this would seem to contradict the trends seen in LEH that suggest decreased frailty.

Finally, prevalence of porotic hyperostosis in the UISC subsample is calculated to be 16.2% (porotic hyperostosis scored as present in 24 out of 148 individuals with occipitals and parietals preserved). In the New York African Burial Ground sample, 47.3% of individuals had at least one observable instance of PH (Null et al., 2004). The Legion of Honor Cemetery group had an extremely low incidence of PH at 3% (Buzon et al., 2005). The smaller Terry Collection study reported 5.3% incidence of PH (Zarenko, 2014). The wide range of PH prevalence may be due to the absence a universally applied standard for recording PH. Variance of recording methods could translate into perceived variance in the condition.

Since the 1950s, PH was thought to be associated with iron deficiency anemia and thus assumed to be representative of nutritional deficiencies. However, Walker and colleagues (2009) cast doubt onto this relationship, arguing that anemias that cause increased red blood cell death and overproduction of these cells (e.g., hemolytic and megoblastic anemias) are a more likely explanation for PH. This publication spurred a new wave of research into the etiology of PH which overall postures that it may be premature to discard the iron-deficiency anemia explanation entirely, in part due to high co-occurrence with vitamin B-12 deficiency, but concedes that inherited anemias and conditions of low bone mineral density seem a more likely cause (e.g., Ferrando-Bernal, 2023; Oxenham and Cavill, 2010). Similar to PR, then, PH is better characterized as a non-specific lesion of biological stress.

Prevalence of PH in the UISC sample lands somewhere between the reported rates of free and enslaved African Americans from colonial New York and the poor populations of St. Louis and San Francisco. Again, heterogeneity of health/frailty is obscured by the fact that we can only see evidence of PH in those who survived long enough to develop it. Overall, a conservative generalization of metabolic stress markers in the UISC is that this sample experienced similar, if slightly increased, levels of metabolic stress relative to similar populations and likely was not a notably frail group.

In the UISC sample, there were no significant sex differences in caries frequency, LEH, PH and PR. Age was also tested for a relationship with PH and PR, but once again, a meaningful relationship was not found. The implication is that metabolic stress load was experienced equally between males and females. This is not unusual for similar populations. For instance, in the New York African Burial Ground sample, males had a higher prevalence of PH, but this difference was not statistically significant (Null et al., 2009). The Belleville St. Thomas Anglican Church cemetery found significant differences in caries frequency across age cohorts, but not between sexes (Buzon et al., 2005; Saunders et al., 1997). The Santa Clara Valley Medical Center Cemetery also found that caries frequency was not significantly influenced by age or sex. It seems that the biological burden of poverty or marginalization (as some of the UISC population were institutionalized) is borne equally, at least with respect to these variables, between the sexes; males and females tend to express the same rates of osteological markers of metabolic stress, suggesting that socioeconomic status and its interaction with discriminatory practices are the primary determinant of metabolic stress load.

In the UISC specifically, PR and PH had no relationship with age at death, as aforementioned, or birth location. In contrast, there was a significant difference in PR prevalence between the two death cohorts. The later death cohort (1940-1952) had higher rates of PR than the earlier death cohort (1929-1939), but there was no difference in PH prevalence between the two. Birth cohort was not significant to either PH or PR. The elevated incidence of PR, but not PH, in the later death cohort may be interpreted a couple ways. One possible interpretation is that frailty lessened, allowing for greater survivorship of stressors and the ability to live long enough to develop PR. However, if this were the case, PH prevalence would also be expected to increase in later death cohorts, and this is does not occur. A second interpretation is that the types of metabolic stress experienced changed throughout time. Perhaps prevalence of PH and PR reflect different origins of stress on the body, and one of those types of stress became more common while the other did not. Unfortunately, due to the recognition of both PR and PH as non-specific lesions (i.e., diverse range of potential causes) and limitations of historical context, it may not be possible to confidently assert more than this.

While PR has several causes, one etiological pathway is via disease/infection, a less likely origin for PH. If increases in PR in the later historical context reflect changing stressors rather than shifts in frailty, one potential explanation may be increasing immune stress. This could be attributed to rates of rapid population growth in the area. According to U.S. census records, the population of Santa Clara County inflated from 11,912 in 1860 to 174,949 by 1940. As in many places experiencing population explosion during the time, infrastructure development had a difficult time meeting basic needs such as waste management, clean water, sanitary living environments, and general public health (Bright, 2019; Fonseca and Prange, 2008: 6). Increases in population density are historically mirrored by increases in infection load, and we do see evidence of this in the Santa Clara Valley through primary documentation (e.g., Evening News, 1902) describing battles to stem epidemics of "consumption" (tuberculosis).

Though PR prevalence has a statistically significant relationship to death cohort, its presence/absence has no notable association with notch volume. In a hierarchical multiple regression, after controlling for "base" variables related to notch volume, the addition of PR as a covariate does not improve the model at all. On the other hand, the consideration of PH presence/absence does improve the regression model significantly ($p=.002$). The sign of the coefficient associated with PH is positive, meaning that presence (not absence) of PH is correlated with larger notch volume. Given that the manifestation of PH indicates that the body is under metabolic duress, it is not immediately clear why the presence of this condition is not associated with a smaller notch volume. However, as mentioned in the previous chapter, it is possible that a PH lesion indicates survivorship and greater capacity for metabolic resilience. This lessened frailty may confer some protective advantage against notch narrowing, even in the face of high labor intensity. The natural question to follow this is: why do we not see the same trend between PR and notch volume, if it is also indicative of metabolic stress? I speculated earlier in this section that in this particular population, PR and PH prevalence may be reflective of different types of metabolic stressors. It is not possible to be more precise given the non-specific nature of both conditions. If this is the case, then the same pathway that confers individuals expressing PH with protection against a narrowing of the intercondylar notch may not function the same with the stressors causing PR.

The strength of the relationship between PH and notch volume allows rejection of the null hypothesis that metabolic stress does not impact notch growth, but with a caveat. While notch volume does seem to be linked to metabolic stress to some degree, the lack of an association to PR indicates that this relationship is complex. The significant interaction term of PH and occupation in the final regression model (Table 5.18) may seem to suggest that people more likely to experience metabolic stress are also more likely to endure hard labor, but labor intensity is inversely related to notch volume. In other words, PH presence is linked to larger notch volumes, while higher labor intensity is correlated with lower notch volume. This somewhat confusing relationship may be explained by a confounding variable, yet unknown, that impacts gross morphology differently depending on the type of metabolic stress experienced.

Due to the preservation limitations that prevent consideration of cribra orbitalia, LEH, and caries frequency in a more thorough capacity, it is difficult to take a definitive stance on the nuances of acceptance/rejection of this null hypothesis (i.e., considering partial acceptance in some capacity). It is necessary to expand the sample size to confirm the results presented in this section and expand on a discussion of what types of metabolic stress are more influential. More robust results will also enhance explanations of potential pathways for the biological relationships discussed.

6.5 IMPORTANT LONG BONE ROBUSTICITY TRENDS IN THE UISC SUBSAMPLE

The null hypothesis discussed in this section is that mechanical stress of the long bones is not related to intercondylar notch volume. To test this hypothesis, I examine four measures of long bone cross-sectional robusticity: femoral robusticity index (FRI), femoral midshaft shape (FMS), humeral robusticity index (HRI), and humeral midshaft shape (HMS). FRI is a proxy for general mobility level as bipedal locomotion is the principal mechanism via which the lower long bones experience mechanical stress. Prolonged cycles of loading stress throughout the life course stimulate bone deposition. Peak bending stress is experienced at the midshaft, and thus this is the primary location of bone reinforcement. FMS does not indicate magnitude of experienced mechanical stress, but rather directionality. A circular FMS (score of 1.0) indicates significant multidirectionality of movement, while an FMS above or below 1.0 is reflective of unilateral movement. Due to the nature of bipedal locomotion, it is rare for FMS scores to skew heavily in the mediolateral direction, though it is quite possible in the anteroposterior direction. HRI, like FRI, does also suggest degree of mechanical loading of the long bone, but since the humerus is located in the upper limb, reveals information about handedness and specialization rather than mobility. HMS is interpreted much the same as FMS with regard to loading directionality.

Statistical testing demonstrates no difference between male and female values for FRI, FMS, HRI, or HMS. This is rather unexpected given historical evidence of normative gender roles that dictate what is appropriate masculine and feminine work in

American society. I explain this phenomenon through the homogeneity of socioeconomic status in the sample. Differences in occupational titles are likely not reflected by a difference in level of labor/mechanical stress and level of mobility. Because this sample represents the some of the most destitute and marginalized by society, they were likely relegated to the worst jobs. Diversity in movement across a variety of occupations becomes overshadowed by the high degree of labor and the long hours on one's feet. This interpretation is supported by the similarity of average FRI in the UISC sample (120.59) and some of the earliest farmers (2100 B.C.-A.D. 50) from the Sonoran Desert (Males=121.2, Females=120.5; Watson and Stoll, 2013). In another study of populations in a range of mobility groupings from late industrialists (post-1900 American) to Archaic Paleoamerican hunter-gatherers, UISC FRI matched most closely with Historic Great Plains equestrian hunter-gatherers and Late Woodland "incipient horticulturalists" (FRI=120.95; Wescott, 2006: 202). However, it should be noted that Wescott (2006) also demonstrates that the least mobile groups – industrialists – have higher FRI scores than hunter-gatherers, suggesting that the relationship between FRI and mobility may be more complex than we understand, perhaps complicated by interpopulation genetic differences. Another possible explanation for this seemingly contradictory outcome is that hunter-gatherers spend less time actively laboring (i.e., more leisure time) than agricultural and industrial groups (Dyble et al., 2019). Historical Western industrialist groups endured some of the lengthiest working days, which may compensate for the overall decreased mobility and explain contradictory patterns in FRI.

The average FMS value for the UISC sample is 0.96, indicating a lack of strong unidirectional movement and a tendency toward oscillation between torsional, lateral, and anteroposterior movement. FMS measures from the Early Sonoran farmers examined by Watson and Stoll (2013) demonstrate a significantly greater degree of platitude with an average FMS of 1.12. Average FMS of the UISC sample is notably less than those seen in the variety of populations reported by Wescott (2006), as no averages were reported below 1.0. For the populations best matching the UISC in FRI value, the average FMS reported was 1.10 (Wescott, 2006). These comparisons reveal two important pieces of information. First, tendencies, even for other contemporaneous industrial populations, are for the anteroposterior dimension to be greater than the mediolateral aspect, as evidenced by the frequent reporting of scores above 1.0. UISC values reflect the opposite, a greater mediolateral aspect, but this does not necessarily indicate anything about labor. Osteological aspects such as a longer femoral neck and larger biacetabular breadth can increase femoral mediolateral bending stress when standing and walking, and it is possible that members of the UISC demonstrate one or both of these conditions (Ruff, 2017). Measurements of the femoral neck length and biacetabular breadth were not recorded and therefore this cannot be tested, but still should be considered as a possible explanation for higher M-L measurements.

Second, the UISC population overall has a more circular femoral midshaft than populations with greater degrees of mobility. I believe the strongest interpretation of this comparison is that the UISC sample lacked specialization overall. Evidence supporting this conclusion is evident in the primary documentation. For instance, historical documentation lists UISC-760A as a clerk in 1890, 1896, and 1907, a merchant from 1892-1893, and an autocamp “caretaker” in 1930. UISC-859 was employed as a clerk in 1880, carpenter in 1920, and chicken farmer in 1930. Census records list UISC-909 as a maid in 1910, waitress in 1920, and hospital helper in 1930. The precarity attached to low socioeconomic status made job security all but impossible, and many people likely moved between paid positions more rapidly than decennial census records indicate. Lack of specialization in this population would explain why the FMS values point towards multidirectionality of movement. I also argue that this lack of specialization explains differences in FMS patterns between the UISC and contemporaneous populations examined. While some may argue that the populations examined by Watson and Stoll (2013) and Wescott (2006) were more agriculturally centered, while the UISC is considered more industrial, recall that FRI within the UISC actually matched quite nicely to farmer/horticultural groups. Given the prolific agricultural center that Santa Clara Valley represented, perhaps this is to be expected. Therefore, the distinction in FMS, but not FRI, may also be due to specialization (or lack thereof). High turnover in occupation for UISC individuals versus long-term, stable participation in agriculture of other referenced contemporaneous populations may explain the divergence in FMS.

Moving now to birth location, Scheme 1 and 2, this variable also does not influence any of the four robusticity characterizations and may attributed to the explanation outlined above – a lack of specialization and high level of mechanical strain. Birth cohort also has no relationship to FRI, FMS, HRI, or HMS, but death cohort is statistically linked to HMS. Even after controlling for age, HMS and death cohort still displayed a significant association. Death cohort demonstrating a meaningful correlation, while birth cohort does not, bolsters previous arguments that the smaller group sizes in birth cohort can "silence" differences seen between the larger membership groups of death cohort. In other words, the individuals that together create the significant effect are split up over different birth cohorts, making the prior pattern undetectable. This could be tested further with a larger sample size to see if results hold stable or if the statistically significant results are manifest in both birth and death cohorts.

The average HMS for the UISC sample overall is 0.81. For the first death cohort (1929-1939) the average HMS is 0.82, while for the later death cohort (1940-1952) the average HMS is significantly lower at 0.79. This decrease in average HMS indicates that the humeral midshaft shape increased in platymeria over time. Whereas a more circular midshaft represents long term patterns in multidirectional movement, a flatter HMS can reflect the decline in labor over time. As individuals aged, many became "inmates" in almshouses or other institutions and while some did continue to work in some capacity, it is unlikely that this continued with the same frequency or strenuous nature as in early life. As a result, individuals are not performing the same range of activities as often and humeral midshaft shape becomes reflective of unidirectional movement.

Further exploratory analysis with robusticity measures indicates no relationship to cause of death, but for Occupation Scheme 1, FRI varies significantly by occupational category. Post hoc testing shows that construction and extraction occupations are the driving force behind this significant finding, as this group has a much higher FRI average than other groups with a large enough sample size to be included in the analysis: food preparation and serving related occupations, sales and related occupations, farming, fishing, and forestry occupations, production occupations, and the miscellaneous category of "laborer." Among these 6 occupational categories (there are more than 6 categories in this scheme, but only these contained enough individuals to be included in statistical analysis), the biggest difference in FRI is between construction/extraction and laborers. It is difficult to make specific interpretations of results involving the "laborer" category. As seen in the U.S. Census Bureau's "Comparative Occupation Statistics 1870-1930" (1940), laborer exists as a subheading in the tabulation of nearly every occupation category, and some enumerators would specify a field such as "agricultural laborer" or "industrial laborer." For a sample population with less racial skew (the UISC overrepresents whites), it would be a worthwhile endeavor to test whether particular racial groupings are more likely to be referred to as a laborer, a laborer in a specific field, and listed with a particular occupation. However, for the UISC sample, the category of "laborer" was rarely qualified with a particular field.

The difference in FRI averages between laborers and those in construction/extraction tells us that "laborers" overall may have been involved in less intensive, more stationary work than those in construction. Following "laborer," the occupational category with the next biggest difference in FRI from construction was food preparation and serving occupations, followed by farming/fishing/forestry, sales, and finally production occupations. If FRI is indeed reflective of level of mobility, construction/extraction and production occupations must necessitate the highest level of mobility, with "laborer" and food preparation/serving requiring the least amount of mobility. To recapitulate, production occupations in the UISC include carpet weaver, shoemaker, painter, seamstress (Fig. 6.1), newspaper printer, and horseshoer. It is logical that construction would have the highest average FRI of the occupations included in statistical analysis as it requires a high degree of walking and carrying of heavy loads, which increase the bending stress on the femoral diaphysis.

Given the range of production occupations represented and the potential for a substantial amount of labor to be carried out in a seated position within these particular jobs, however, it is fairly surprising that this category also has a notably high FRI. There are several possible explanations for this pattern. First, people in production occupations may have needed to supplement income and carried out additional labor roles not listed in historical records. For instance, seamstress work was highly seasonal, and many left the better-paid, but intermittent position for lower-paid, more stable year-round jobs (Gamber, 1997). Laboring in multiple positions or oscillation between two seasonal positions is difficult to generalize when historical records only offer "snapshots" of lived experiences, and for this occupational category, FRI may not accurately reflect mobility levels of listed occupations. Second, it is also possible that production occupations had a high turnover rate that census records cannot reflect, although this does not seem likely as there is at least some degree of specialization needed for most production jobs. A third and final consideration pertains to methodology — FRI might reflect more than general mobility, in this case, perhaps repeated cycles of sitting and standing. This last consideration is based on research demonstrating that "cyclic applied loads often stimulate cortical growth, leading to changes in cross-sectional geometry that can improve a bone's resistance to loading" (Abufaur and Bhramdrat, 2023; Devlin and Lieberman, 2007: 602; Robling et al., 2014). While bone can respond to high magnitude static strain, it (re)models most efficiently under conditions of cyclic stress (Knüsel, 2002). Further access to historical documentation and methods testing is necessary to determine which potential explanation is most likely.

Figure 6.1. *Daguerreotype image of an American seamstress published ca. 1853, Library of Congress digital archive.*

Despite strong differences in FRI detected in Occupation Scheme 1, the same cannot be said for Occupational Scheme 2. The erasure of this patterning can be attributed to the use of aggregated groups in Scheme 2, which introduce "static" that minimizes the distinction that the construction/extraction group possess in Scheme one. Though it may seem contradictory that the same variable "occupation" can give two results when measured differently, this was exactly the point of utilizing two different schemes in the methods and analysis. At different points throughout the analysis and interpretation, key relationships would have been missed if I had relied in totality on the stratified or aggregated scheme alone. These schemes work together to help build a more thorough understanding of patterning and operations at different levels of measurement.

Another relationship of note is that between age at death and FMS. The calculated regression equation points to a negative relationship between age at death and FMS. For the UISC, this negative association means that younger individuals tended to possess a diaphysis that is more circular in nature and drifted towards an asymmetrical, flatter FMS over the life course. This trend is similar to that noted by Wescott and Zephro (2016) in a study of 395 Terry Collection adult white females and males from the 1850s-1970s. They also note an aging trend in FMS that represents change from circular to platymeric midshafts. Rockhold (1998) examined individuals from the early 19th-late 20th century in America and reported the same trend of increasing flattening. In both cases, the authors have pointed to declining activity/mobility as the explanation for these diaphyseal changes, though I also emphasize changing mobility dynamics (directionality) as well. Feik and colleagues (2000), in a study of modern Australian individuals aged 20-97, actually note the opposite phenomenon – a trend towards a more circular femoral diaphysis. The lack of homogeneity in results across populations bolsters the argument that FMS is contextually, culturally, and socioeconomically dependent.

An ontogenic perspective highlights the continuous nature of plasticity along the diaphysis. In early childhood, the femoral and tibial diaphyses are circular, as they have experienced relatively little loading stress at this point (Gosman et al., 2013). By the onset of puberty, this circular patterning has typically been disrupted for a flatter shaft via increased endosteal deposition that expands the cortical layer of the bone (Gosman et al., 2013; Hubbell et al., 2011; Weaver and Fuchs, 2014). Age trend correlations allow for comparisons to early life development and a mapping of bending stress throughout the life course. This perspective is not complete, though, without considering changes in the osteological processes in later life. Although bone deposition and resorption continue to occur throughout the entirety of an individual's life, the capacity for bone to stimulate osteoclast and osteoblast activity does diminish (Li and Stocum, 2014). Bone maintenance becomes disrupted as resorption outpaces deposition and often leads to osteoporosis. Osteocyte viability can also decrease over time, particularly in individuals experiencing menopause, dearth of mechanical stress, and glucocorticoid excess (Bellido et al., 2014; Burr and Akkus, 2004). Thus, while trends in FMS are perhaps most affected by mobility factors, we cannot interpret results without considering underlying osteological processes. For the UISC, the females included in the sample are elderly, but there are so few that menopausal considerations are not expected to be a cause of FMS drift. Moreover, individuals in almshouses in Santa Clara Valley remained relatively active and engaged in local horticultural processes; this, coupled with changes in activity to explain dominant mobility directionality, likely explains the trend away from a circular diaphysis.

Length of residence in California also plays a notable role with regard to long bone robusticity. HRI and CA residence are significantly related; as length of residency increases, so too does HRI (regression equation: HRI = .071*(length of CA residence) +

87.127). Stature is not included in the regression equation as it does not add any explanatory power to the model. The crucial piece of information here is that HRI increases with length of California residency, but not overall length of country residency. There must be something unique about labor patterns in this geographical area that increases strain in the humerus and spurs bone deposition along the diaphysis. The industry that really made Santa Clara Valley distinct from other areas across the U.S. was its world-recognized (at the time) prominence in agricultural production. The oak trees and grasslands that had covered the landscape in the time of the Ohlone were razed by the end of the 1700s, post arrival of the Spanish (Friedly, 2000). By the mid-1800s, large cattle ranches established to meet high demands for animal products, such as leather, had driven native species like elk into local extinction (Friedly, 2000). American frontiersman drove rancheros off their land by launching numerous financially draining lawsuits. All of this set the stage for exploitation of the fertile valley for the production/exportation of grains, fruits, vegetables, and a variety of animal products.

Despite the proximity to large urban centers such as San Jose and San Francisco that were dominated by production (e.g., factories and railroad work), jobs involving working of the land were most prominent in Santa Clara Valley, also known as the Valley of Heart's Delight. Out of the 186 documented UISC individuals with at least one preserved femur, 36 were explicitly listed as being involved with agricultural work. It does not take a large leap of faith to infer that a large portion of the 79 individuals listed as "laborers" were also likely involved in agricultural and farming work. Thus, a majority of those in the UISC were involved in the dominant industry of the valley. This type of work is rigorous, and due to its heavily seasonal nature, likely needed supplementation by other intermittent work which would probably be similarly demanding. Long-term participation in agricultural and extraction work would promote humeral robusticity due to the magnitude of osteological stress experienced. This unique occupational pattern explains why HRI is significantly correlated with length of residency in California, but not general residency in the country – labor patterns in Santa Clara Valley were unique from big cities and other rural regions.

Another telling evaluation of robusticity and shape measures is a sidewise comparison. By comparing robusticity and diaphysis shape for the left and right sides within each individual, aggerated results can identify directional asymmetry in the larger group. In this section, only femoral measures will be discussed. As per standard osteological methods, only the left humerus was measured, and values from the right humerus substituted when the left was ill-preserved or missing. This means that I do not have paired values (a left and right value) for the humeri of UISC individuals. Rectification of this limitation is a goal of subsequent study of the UISC. With regard to the femur, however, the overall UISC sample has significant directional asymmetry only in FRI, with the left femur expressing a higher index. When separating the sample by sex, females have no difference in left and right FRI, FMS, notch volume, or NWI. Males only have significant asymmetry of FRI ($p=.003$) with the left femur displaying a higher robusticity than the right. Female labor was historically centered in the domestic sphere, and the majority of the females in the UISC conformed to this trend by being involved in labor related to food and cleanliness. These types of labor would not involve high mechanical loading stress, so even if low levels of asymmetry developed due to footedness, it would likely not manifest at a statistically significant level.

When separating the sample by birth cohort, both birth cohorts 3 and 4 exhibit significant asymmetry of FRI and FMS, with left femora being more robust and right femora with a more circular diaphysis (FMS). Of the two death cohorts, only the second displays any asymmetry of the femur. The group that perished between 1940 and 1952 had a more robust left femur than right. In the birth- and death- cohort analyses, none of the early birth cohorts nor first death cohort demonstrate any directional asymmetry. The development of directional asymmetry perhaps parallels changes in labor trends and intensity. To be more specific, as Santa Clara Valley transitioned from more of a smaller, family-scale production force to an intensified, magnified agricultural power that was known across the world, the stress on the lower limbs increased and was experienced for a longer daily duration. This combination, in addition to the prevalence of having a dominant leg, is a strong possible explanation for the development of femoral robusticity asymmetry when previously there was none. In this manner, trends in robusticity reflect historical context and changing industry patterns.

By occupation, there is some limited evidence of asymmetry. In Occupation Scheme 2, Group 4 (food preparation/serving, production, transportation/material moving occupations) is the first group that demonstrates notch volume asymmetry. Notch volume asymmetry is highly significant ($p<.001$) with the average volume of the right femur exceeding that of the left by about 800mm^3. The explanation for asymmetry in notch volume is difficult, given that volume does not seem linked to femoral robusticity or diaphyseal shape. The lack of asymmetry in FRI and FMS indicates that general level of mobility and primary directionality of movement are relatively stable between the left and right limbs.

One possible explanation is previous ACL injury. Clinical studies indicate knees that have experienced previous ACL rupture tend to have more constricted notch parameters than knees without injury experience (Babalola et al., 2021; Jha et al., 2022; Ouyang et al.2016; Wang et al., 2020). Post-ACL injury and even after reconstruction of the ligament, the intercondylar notch tends to be reduced in size compared to pre-injury dimensions. Because Group 4 includes what we know to be some of the occupations with the highest intensity of labor, this group may have disproportionately experienced ACL injuries in the dominant leg. As handedness does tend to parallel footedness (e.g., Barut et al., 2007), most individuals favor the right leg as the dominant lower limb. This means that the right leg would be performing a majority of the manipulations, while the left leg serves as a stabilizer and experiences most of the mechanical stress. As exemplified in a study of female soccer players, the stabilizing (non-dominant) limb can experience higher risk of ACL injury (Wang and Fu, 2019). If ACL injury was common in Occupation Group 4, then, it could explain the discrepancy in notch volume between the left and right femora.

One limitation to this explanation is that strong limb dominance would likely be expressed in asymmetry of FRI, which we do not see in Occupation Group 4. It may have been the case that post-ACL injury, limb dominance changed sides out of necessity, erasing robusticity differences, but this seems relatively unlikely. Thus, an alternative explanation is that the *type* of movements experienced by the knee influence notch morphology. It is possible for general mobility levels and primary directionality of labor/movement to hold stable while experiencing different types of movements. For instance, flexion and extension are both unilateral movements, but of a different type. So, perhaps asymmetry in types of movements experienced leave FRI and FMS unchanged while causing a discrepancy in notch volume.

Final testing of the relationship of notch volume to robusticity measures and diaphyseal shape involves use of hierarchical multiple regression, in which "base" variables are controlled for in the first block, and FMS, FRI, HMS, and HRI are assessed as the second block of covariates. In this scenario, only the addition of HRI as a covariate improves upon the base variable model significantly (p=.004). Just as important as the relationship between notch volume and HRI is the *lack* of any association between notch volume/NWI and femoral midshaft measures (robusticity and shape). The lack of an association between these variables adds to the previous argument that notch volume is less related to mobility level and its directionality and is more associated with specific types of movement. Due to the humeri not being load bearing bones for bipedal locomotion, their robusticity is reflective of upper limb-centric movements that tend to be more occupationally specific. Taken together, the relationships both seen and *not seen* with regard to notch volume suggest that movement type, rather than general activity level and intensity of loading stress, has a larger influence on resulting notch volume. Overall, the null hypothesis that mechanical stress experienced by the long bones is not related to notch volume can be rejected to a degree. There is a clear link between HRI and notch volume, and though it is surprising given that the intercondylar notch is located in the femur and not humerus, it is still evidence that mechanical functions do impact the notch space. Future research should include a measure of notch depth as another way of characterizing changing notch space.

6.6 ASSIGNED RACIAL CATEGORIES AND GENETICS

This section tests perhaps the most important hypothesis of this dissertation and the heart of the research direction. The null hypothesis for this section is that genetics do not have any influence on notch volume. Two primary assumptions that biomedical studies make with limited testing of veracity is that genetics are the main determinant of intercondylar notch morphology and that socially assigned racial categories reflect genetic heritage. The acceptance or rejection of this hypothesis will indicate whether an anthropological perspective really can benefit clinical research regarding the intercondylar notch. If genetics are indeed strongly linked to notch volume, then the perspective of future research must shift towards risk mitigation. In other words, not everyone with a stenotic notch experiences an ACL impingement or rupture. If genetics really are the primary determinant of notch space, then the next question worth asking will be, are there certain movements or activities that put a person with a small notch at risk, and is there any type of physical therapy (exercise) that might abate that risk? However, in the alternate scenario where genetics are not a covariate of note, then an anthropological perspective will absolutely benefit research concerning this locus. It will mean that other contextual inputs must be considered, such as socioeconomic status and occupation. If notch volume is independent from genetic considerations, then it will also indicate that it is possible to build robust injury prevention programs and look beyond DNA, and race, for risk factors.

To test this hypothesis, individuals were grouped into genetic clusters based on patterns in expression of nonmetric traits. The genetic clusters presented in this research represent conservative groupings, due to the elimination of squatting facets from consideration. Results of fetal studies do indicate that the development of facets in particular locations has a large genetic component (Weiss, 2017), but since squatting facets do seem to also be heavily shaped by behavior as well, I have chosen to leave the tibial and talus facets out of the final analysis. The strength of the resulting nonmetric clusters, as evaluated by how well the clusters maximize intergroup differences while minimizing intragroup ones, was rated as strong by SPSS programming. It is likely that the strength of the clustering could have been improved by the use of cranial nonmetric traits, but preservation issues in the sample led to the filtering out of most of these cranial traits. Future research directions in this area will include expansion of the sample, so that it is possible to evaluate whether the inclusion of cranial nonmetrics increases the reliability of the clusters and if it changes the acceptance/rejection of the null hypothesis.

If the cohesion of the nonmetric clusters is strong, they should reflect ancestry to a relatively high degree. In testing this hypothesis, however, it became apparent that birth locations did not map in a predictably patterned way to the nonmetric clusters. Rather than this destabilizing the strength of the model, I argue that it instead lays bare a limitation of the data themselves. As many individuals in the UISC were born in the United States, heterogeneity of ancestry is not clear from a birthplace listed as "Iowa," for instance. American birth locations render invisible the variety of ancestral lineages present in the collection. Limitations of access to parental birth locations, as well as contradictions in documentation, also pose challenges to looking to a previous generation for more ancestral information. It may be worth some genealogical work to try and trace back ancestry by tracking down more primary documentation, but this is time-consuming labor and not within the scope of this dissertation.

As for the relationship between assigned racial categories and the computed nonmetric clusters, analysis is limited because after individuals with excessive imputation of nonmetric trait presence/absence, only two racial categories included enough individuals to meet statistical testing parameters. From these two racial groups (white and Asian individuals), it is clear that there is no association between race and nonmetric clusters (p=.900) and no relationship between presence of each nonmetric trait and prevalence within assigned racial categories (a different method of testing the previous result). In the future, it is necessary to expand the sample size so that racial categories are represented equally, but these results do suggest that “race” is not a meaningful category by which to analyze and understand notch volume. It is particularly telling that a majority of the UISC sample is categorized as “white” but still strongly separates into different nonmetric clusters. This testifies to the ways in which California consolidated many different white ethnicities into a single bloc, even the Irish who remained on the outskirts of this label throughout much of the U.S., in fear of rising numbers of Asian immigrants (e.g., Barkan, 2007; Daily Alta California, 1876, 1881; Jacobson, 1984; Mink, 1986; Prince-Buitenhuys, 2016).

Further exploratory statistical testing indicates that midshaft measures, length of residence in the U.S. and California, and stature have no bearing on nonmetric cluster membership. Length of residence could be related to genetics if recent immigrants tended to come from different continents than earlier immigrants, but these results suggest otherwise. It is a bit confounding that stature does not map to genetic clusters, given that height is 60-70% heritable (Muthuirulan and Capellini, 2019). However, the diverse literature on stature is also quite clear that inability to reach inherited height potential can be caused by a number of factors including intergenerational signals (epigenetics), malnutrition, metabolic stress, and any of the nearly 700 gene versions that have been implicated in stature variance (Leroy and Frongillo, 2019; Hauer et al., 2019; Ramakrishnan et al., 1999). Therefore, it is conceivable that in this small population that does demonstrate evidence of metabolic stress, and likely endured chronic stress due to low socioeconomic status, that these biosocial conditions complicate the relationship between genetics and stature. However, I would be remiss to not mention that these cluster groups may not be objective representations of genetic relatedness, as it is possible there are other unconsidered or hidden factors influencing results.

Cluster groupings have no bearing on NWI ($p=.994$) or notch volume ($p=.387$) leading to the conclusion that biological contributions seem to have very little influence on notch morphology, and I am unable to reject the null hypothesis in this case. The effects of metabolic stress and labor greatly outweigh those related to genetics and ancestry. While this conclusion might be discouraging to the biomedical community who have been invested in the notion that genetics determine most osteological outcomes, I argue that it should be considered good news. The fact that genetics are not the primary determinants of outcomes at this locus means that it is indeed possible to influence notch volume throughout the life course. No single cluster based on nonmetric traits showed a tendency towards a significantly larger or smaller notch, which suggests that no person is “genetically predisposed” to notch stenosis, in contradiction to some of the race-based assertions in the literature (e.g., Ammar et al., 2021; Shelbourne et al., 2007). However, it may be possible to explain what seems like racial differences in notch size through commonalities in shared experiences. Since genetics did not determine notch size in this population, it likely is not an influencing factor in modern people either, but more research is warranted.

There is hope in this conclusion. With the knowledge that metabolic and mechanical/labor stress impact notch volume, further research can help deepen the understanding of these relationships and put them into practice. Collaboration with physical therapists may aid in developing preventative regimens that expand and/or maintain notch volume. Many people who rupture or impinge their ACL experience a noticeable decrease in intercondylar notch dimensions of the affected knee; results from this dissertation may lay the groundwork for programs that safeguard against future re-injury. Moreover, the inability to reject the null hypothesis strongly supports the need for an anthropological lens in medical studies. One cannot glean all relevant health information about a person from their genetic code, and regardless, genetic homogeneity is not reflected in the racial groupings still used by modern medical research anyway. We are not able to understand the outcomes of biology without some reference to life history. What kind of stress did/does the body experience? How is it distinct from others around them and why? Is there a larger societal-level issue that can explain patterns in biology? Clinicians tend to focus on proximate causes and risk factors (i.e., do soccer or tennis players suffer from more ACL injuries?), but to truly work towards decreasing injury rates and comprehension of risk patterns, we must broaden our focus to include the social dimensions of bodily experience on both an individual and group level.

6.7 INTERACTION BETWEEN THE HYPOTHESES

In this section, I look at the overlap between the three main hypotheses tested and discuss the regression equation that unites the significant variables. The final regression equation is: Notch Volume (mm^3) = 17846.881 - 482.961*Occ2 + 370.498*Stature + 9.831*(CA*HRI) + 617.659*(PH*Occ2) -187.762*(HRI*YOD). The signs on each of the coefficients reveal the relationship each covariate has with the dependent variable, notch volume (measured in millimeters cubed). For instance, the coefficient of the Occupation Scheme 2 variable is negative. Since coding of that occupational scheme is ordinal, with lower numbers representing lower labor intensity, a more labor-intensive occupation should result in a smaller notch volume. Stature exerts a positive influence on notch volume and, based on the standardized coefficients shown in the results chapter (Section 5.6), is the variable with the greatest influence on notch volume. From an allometric standpoint, this makes sense. Larger bodies necessarily have larger bones, and as it seems, larger spaces in those bones, like the intercondylar notch. Length of residence in CA and HRI trend together and exert a positive influence on notch volume.

The absence of PH has the ability to zero out the interaction term (PH*Occ2), but its presence mitigates the negative effect of Occ2 on its own. It is interesting that PH by itself is not a variable of significance ($p=.097$), but when interacting with Occ2 it gains meaning. The importance of this interaction term is evident by the standardized coefficients of the covariates. The ß of PH*Occ2 is about three times the standardized coefficient of Occ2 alone demonstrating the power that this interaction holds over the final intercondylar notch volume. In this equation, PH moderates the effect of mechanical stress on the notch volume. For instance, Occ2 alone decreases notch volume as labor intensity increases. But when PH is present, Occ2 does not have the same ability to shrink notch parameters. I argue that the most likely explanation for the significance of this interaction term is that expression of PH indicates that an individual was healthy enough to survive metabolic stress and this constitution may convey some protection against notch narrowing even in the face of high labor intensity. Survivorship of a metabolic stress insult might indicate something larger about the ability maintain biological homeostasis to a degree, which could also translate to a reduction of risk for notch stenosis. The possibility of the relationship between these two variables reflecting an underlying mechanism or pathway is worth investigating in the next research stages.

In the final interaction term (HRI*YOD), HRI determines the strength of the effect exerted by death cohort. If HRI is near or equal to one, then this term becomes a true reflection of year of death. If HRI is less than one, the effect of death cohort is reduced, and if HRI is greater than one, than the effect of YOD is compounded. This interaction term indicates the importance and intertwined nature of labor specialization and temporal context. Notably absent from this model is the variable of race. Its lack of a meaningful relationship to intercondylar notch volume is further evidence against race as a biological reality. Race is not "written" into our genetic code. Our genetics reflect ancestry in the way that groups living in disparate environments have developed adaptations to those particular regions, but the constructed categories of race often complicate, bisect, and ignore ancestral groups. Race as a social construct becomes "real" in the ways that it mediates access to resources and societal norms. Morphological features are used to designate in-group status. This regression model makes clear that what is important to morphological outcomes, in this instance, is not our DNA but the way that socioeconomic status structures life chances, including occupational opportunities, social mobility (or lack thereof), and metabolic stress.

Overall, this regression equation conservatively explains 61% (adjusted R^2), and optimistically 64% (R^2), of variance in notch volume in the UISC. Although a majority of variance is explained, it is worth further literature review and hypothesis testing to find other relationships that might be missing which could strengthen this predictive model. This regression model also indicates that "base" or demographic variables, and the way they interact with other covariates, are just as important as the variables centered in the three hypotheses put forth by this dissertation. Thus, it constitutes evidence that socioeconomic status, labor, and historical context are crucial to comprehending and predicting biological outcomes.

6.8 THE UISC, WHITENESS, AND SOCIAL INEQUALITY

Interethnic and interracial interactions were not always rife with antagonism. Prior to the 17th century, these categories were very "malleable" and considered kinship networks, place of birth, language(s) spoken, and even modes of making a living (Bush, 2004: 8; Smedley, 1998). During this early period, race was not perceived as an inherent and essential part of one's identity and blackness was not stigmatized (Bush, 2004; Harrison, 1998). However, the emergence of the African slave trade, colonial expansion efforts, and spread of capitalism all contributed to a change in how race was viewed and constructed (Bush, 2004). The increasing dependence on accumulation of capital through exploitation of cheap labor necessitated a logic that made dehumanization palatable, even easy. It is within this context, then, that we see solidification in the notion that race can determine a person's constitution and worth.

Many likely were enculturated into these racialized views unknowingly, but race relations were also actively manipulated in the political arena. For instance, Bacon's Rebellion in Virginia (1676) made clear that shared experiences of exploitation allowed transracial solidarity that proved a legitimate threat to current modes of forced labor. Gripped in fear that an alliance between enslaved Africans and European bond-laborers could upend ill-gotten gains, planter elites fervently worked to prevent this solidarity from including Native populations (Zinn, 1995). Rifts were sown by spreading narratives lauding the mythos of whiteness. White bondage workers and other indigent whites were told that their complexion testified to their superiority and "to maintain this status, they needed to place their allegiances with those in power who had the resources and could divvy up the benefits" (Bush, 2004: 9). Foreshadowing the one-drop rule that would be codified in the 20th century, elites made promises of good fortune that could be granted given that racial homogeneity was maintained. In a way, this promise was fulfilled by what Du Bois calls a "psychological wage" (1998: 700-1). Though many white individuals received poor wages like other marginalized groups, they had the benefit of seeing people who looked like themselves prominently in all American institutions. They had access to the best schools, were given deference in public spaces, and filled the courtrooms and police departments. This psychological wage of power was enough for many to overlook destitution as evidence against white racial superiority.

Social relations in California diverge to a degree from the trends seen on a national level, given its unique racial diversity. It is only in California that we see such an extensive collection of people from various ethnic backgrounds living and toiling together in the same communities, resulting in "peoples who had not before thought of themselves as a single group" constructing a novel collective identity (Bottoms, 2013; White, 1986: 397). This group carried the label of "white." The first notable acquiescence to the category of whiteness came during the formation of the California Constitution. The Treaty of Guadalupe Hidalgo placed the constitutional committee in a difficult position — Mexican Californians were guaranteed citizenship, but how were they to grant this without allowing a means for indigenous groups to also qualify for citizenship? In the end, the state constitution granted citizenship and suffrage to white American males and 'every white male citizen of Mexico' while actively ensuring that California

Indians were clearly excluded from the fold of whiteness (Almaguer, 2009; Glenn, 2002; Wilson Moore, 2003: 103).

What leeway was given to some Mexicans was not granted to black Americans. Although the mythos of the gold rush drew numerous black individuals to the mines, whites of all ethnicities fervently resisted the involvement of free or enslaved blacks in the mining industry, claiming their presence "devalued" what was otherwise an "honorable livelihood" (Roberts, 2008: 12). The state swiftly moved to ban slavery, but the motivation was less than altruistic. California was a state of pioneers and (primarily) men looking to make their way in the world, and they engendered great animosity towards the potential cheap labor provided by slavery with which they would need to compete (Almaguer, 2009). The fugitive slave law in California required that enslaved persons who had escaped to California must be sent back to their enslavers, clearly underlining the public sentiment directed towards persons of color on the Western frontier (Wilson Moore, 2003).

Experiences of exclusion strengthened kinship of racialized communities, and before the onset of the Civil War, sizable black communities were established San Francisco, Maryville, Stockton, and Sacramento (Roberts, 2008). These communities had their own newspapers, schools, libraries, theaters, and churches, primarily developed due to exclusion from the right to attend public schools, homestead public land, be involved in the justice system as jurors or give testimony, and barred from voting rights (Almaguer, 2009; Roberts, 2008). Subsequently, many members of these black communities worked towards achieving civil rights. One of the primary hurdles that black Californians identified as barring them from full citizenship was the legislative attempts to produce a homogenous racial group of "non-whites" (Bottoms, 2013). For instance, in the case of the *People v. Hall* (1854), the court ruled that persons of Chinese ancestry could not testify against white Americans in court due to inferior intellect, merit, and reliability. This ruling relegated Chinese individuals to the same sub-white status as Native and black Americans. Recognizing that association with these other stigmatized groups stymied their calls for civil justice, black Californians "took the initial steps in distinguishing themselves from other nonwhites by limiting their requests for a change in a law to themselves" (Bottoms, 2013: 32). It seems that this tactic was effective to a degree and that California demonstrated willingness to relax testimony laws regarding black Californians (Bottoms, 2013).

In 1870, the Fourteenth Amendment was ratified, and "unimpeded" citizenship was won for black Americans, but segregation of school systems remained the norm until a decade later (Almaguer, 2009). Regardless of this new freedom, black Americans were still relegated to occupations of the lowest class in positions such as bootblacks, porters, cooks, barbers, waiters, and overwhelmingly unskilled day laborers (Almaguer, 2009: 40). Some attempted to establish farming communities but were largely ousted by violence from established white farmers (White, 1986). Black Americans shared a particular animosity towards the Irish (vestiges of fierce job competition at the lowest rung of the social ladder brought to the West through migration) and unions, which were synonymous with barriers to black employment (Almaguer, 2009). This historical ethnic tension was likely exacerbated by the new ability of the Irish to achieve the racial designation of "white" in California. Historical documents repeatedly show that persons of various European heritages self-identified and were ascribed as white, a label that subsumed diversity in ethnicity & nationality through the racialization process (Almaguer, 2009: 11). Though scholars like Bottoms (2013: 17), claim that Californians "[drew] a color line through their laws that divided the world into two simple categories: white and non-white," a survey of the literature suggests that one of these groups experienced internal contention while the other did not. Ethnic groups granted the privileges of whiteness established a stable hegemonic bloc, with relatively little conflict to supersede one another. This was not the case among the "non-white" category, in which groups constantly attempted to prove they were superior to other non-whites.

The onset of high levels of Chinese immigration only served to complicate the stratigraphy of non-whites in California. Chinese immigration was initially openly accepted and petitioned for in California as a source of low-cost labor, likely due to racialist thinking that the Chinese were "inferior and unassimilable" and would "inevitably die out and vanish in the presence of superior races" (White, 1986: 402). As rising numbers of people of Asian descent moved to the West coast, perception shifted to regard this immigration as job competition that needed to be ousted before they outnumbered white Californians (White, 1986; Wilson Moore, 2003). To create a hostile environment for this group, California imposed an immigration tax of $50 per person for Chinese immigrants and Irish workers founded a Workingmen's Party in San Francisco that worked tirelessly to exclude Chinese immigrants from the workforce and citizenship (Wilson Moore, 2003). Rumors of leprosy being a Chinese illness were weaponized to portray the Chinese as “dirty” and further color public sentiment against them (Shah, 2001). Despite discrimination against Asians in California and the federal employment of the Chinese Exclusion Act, immigration to the United States and the West Coast from Asia continued steadily (Jacobson, 2000).

In the Santa Clara Valley specifically, white boosters looking to entice the “right kind” of white people to populate the valley portrayed the region prior to Anglo settlement as a wild and underdeveloped landscape whose potential escaped the grasp of the Ohlone, Spaniards, and Californios (Knox, 1902; Tsu, 2006: 21). The work of the boosters was efficient: from 1890-1900, the American-born white population in California grew by approximately one-third, and in the following decade it increased by about 60% (Tsu, 2006: 33). The increasing whiteness of the population was mirrored in almshouse demographics which, by the early 1900s, were overwhelmingly filled with native- and foreign-born whites (e.g., Prince-Buitenhuys, 2016). In most primary and secondary documentation, it is clear that California did not particularly consider whiteness a kaleidoscope category. There is very little differentiation made between native-born whites and whites of varying nationalities and ethnicities. California is a large state, and there are bound to be regional differences where this is not the case, but in the Santa Clara Valley, the concept of whiteness was employed evenly across all individuals who could pass for caucasian (Daily Alta California 1876, 1881; Prince-Buitenhuys, 2016; Shah, 2011; Tsu, 2006).

In California, some might argue that the primary racial antagonism proffered by whites shifted away from black Americans to new Chinese and other Asian immigrants.

While it is true that rapidly escalating immigration drew white Californians into a "frenzied competition" previously unseen, the scramble to respond relegated to the background longstanding racial tensions between white and black Americans (Almaguer, 2009: 41). However, the reality is that black Californians were never allowed to be in effective competition with European and native-born whites, and therefore were never perceived as a real threat to the value and accessibility of labor positions (Almaguer, 2009). Racial solidarity transcended disparities in social class among whites, and rendered whiteness invisible to its members, except in cases where it needed to be presented in opposition to non-white groups. This was a privilege out of reach for non-whites, who were never able to forget their ascribed racial identities and who needed to navigate the 'white world' in order to survive (Bush, 2004: 6; Du Bois, 2007[1903]).

The nature of a California whiteness that flattened out ethnic differences and largely ignored them explains osteological trends in the UISC. For instance, nonmetric-based clusters do not show distinct patterns in long bone diaphysis shape, robusticity, PH, PR, notch volume, or NWI. Historically contextualizing this information allows for the interpretation that people of different ancestries were treated similarly as long as they were white passing. Animosity was primarily directed at individuals that were clearly differentiated from whites in phenotype. While it is possible that being in the lowest echelon of society minimized differences in societal treatment based on physical appearances (and interpretation of "race"), most primary and secondary documentation continually refers to a whiteness that hides heterogeneity. Given that the documented UISC sample is heavily white but five clear nonmetric clusters were distinguished, this suggests that different ethnicities/ancestries are represented. A relative lack of osteological differences in mechanical and metabolic stress indicate that life experiences for each of the five nonmetric groups did not diverge significantly. The strongest explanation for this pattern is that whites of all backgrounds found their racial identities homogenized in the process of combatting labor competition and enforcing a racial hierarchy. The osteological evidence supports the argument that whiteness is a malleable category whose parameters change based on local contexts, what Lipsitz (2006: vii) argues encourages "possessive investment." In other words, investment in an exclusionary category such as whiteness has a material payoff through unequal access to resources and opportunities that gives future generations of whites the power to continue discriminatory actions.

It is understood that the category of whiteness has not and will not ever be defined in relation to itself. It necessarily creates cohesion within the group by defining who is outside of it. As Robin Kelley argues, whiteness is meaningless without Othered groups (1996). Throughout California history, white racial superiority was challenged by new groups, such as Californian Indians, Mexicans, and Asian immigrants. This moved the polarizing black-white racial tensions away from the spotlight, but only because the longstanding nature of this antagonistic binary was so entrenched in the white worldview that racialized beliefs need not be actively curated. Whiteness in California was still defined in opposition to blackness as it had been historically, but perceived encroaching threats (moral, labor-related, etc.) from other groups triggered an expansion of the usually narrow definition of whiteness. Thus, the work done in this dissertation is not the whole picture. From this sample, we can get a sense of what lived experiences for those in the UISC who were included in whiteness were like, and from this, there is a tangential (perhaps peripheral) understanding of how this affected other races. Because experiences of racial identities are so interdependent, it is not possible even to fully comprehend embodiment of whiteness without sufficient osteological evidence from other groups. The future directions of this work intend to expand the sample size to include more non-white individuals to build a more dynamic understanding of social relations, health, stress, and femoral morphology in the historical Santa Clara Valley.

6.9 LIMITATIONS OF THIS RESEARCH

Many of the limitations noted in this research project come not from methods or interpretations, but the origin of the data themselves: skeletons and documentation. The full UISC skeletal collection is comprised of approximately 1,100 individuals. Due to the questions being asked in this dissertation, I chose to only focus on documented individuals which reduced the sample to under 200 individuals. Within this smaller subsample, there was a clear sex bias. Documented individuals are overwhelmingly male and white. Very few Asians, African Americans, and Hispanics were associated with complete documentation, as is also noted by Vanosdall (2023). Moreover, most of these individuals are elderly. The age bias is linked to the source institutions for the skeletal remains included in this population. The "informant" listed on the death certificates for a majority in the UISC is an almshouse or hospital that provides hospice care and/or care for the elderly.

The demographic homogeneity of the UISC documented sample does not make it unworthy of study, but it does limit what questions can be confidently asked and answered. For instance, the lack of association found between assigned racial categories and nonmetric groupings does not have strong statistical power, as only two races met minimum metrics for inclusion in testing. I have tried to be clear throughout this dissertation when results are impacted by the narrow nature of demographics within the UISC. This research project is meant to be a beginning, not an end. Though I can primarily speak about white, elderly, males, this work is constructing a reference population to which further research will compare other diverse groups. I did not undertake this project with the intention of putting first, yet again, the group that experiences the most privilege in the United States. The demographic limitations of the sample size dictated this group as the focus, but I understand that whiteness cannot be defined or interpreted apart from the groups it has Othered and intend to continue broadening the scope of this research to address this. However, this research is capable of elucidating how the category of whiteness was rooted in notions of supremacy, and therefore has a bearing on the experiences of other non-white groups.

Associated documentation creates additional challenges. Some individuals lack thorough documentation, while others have an abundance. Census enumerators introduce personal prejudice, though intentional or not one cannot say, by choosing whose labor gets recognized with a specific label and who gets relegated to the miscellaneous category of "laborer." Due to the extreme representation of white bodies in this collection (approximately 86% of the overall UISC collection), it is not really appropriate to conduct statistical testing that examines whether whites or other races are more heavily represented as "laborers." However, the use of the catchall term of "laborer" makes it difficult to qualify level of labor and presents a challenge to interpreting long bone robusticity and shape with respect to occupation. Furthermore, without extensive, time-consuming archival research into each individual, I have to rely on census records to piece together occupational history. Censuses are conducted decennially, and consequentially I only get snapshots of jobs worked throughout the life course and sometimes need to make subjective decisions on which documented occupation likely had a greater osteological impact.

Census records can be contradictory. For instance, UISC-806, a white female housewife from Arizona has her father's birthplace listed as both Massachusetts and New Hampshire, depending on the census year. UISC-960, a white male with no listed occupation is listed as being born in New York, New York on his census record, but his draft card reports that he was born in Jersey City, New Jersey. UISC-1000, a white male ironworker from Ohio has his mother's birthplace listed as a different state in every record I could locate including Ohio, Pennsylvania, and Texas. Choosing which record to believe is subjective to a degree. If something is reported identically in a few primary documents and only one record deviates, I follow the majority rule. But this does not necessarily mean that this decision reflects reality. Primary documentation is helpful when I can confidently associate it with the appropriate individual, but can "hide" individuals with common names, lack of a permanent domicile, or high levels of turnover in occupation. The State's practice of making legible individuals via documentation has always been a form of structural violence (Scott, 1999). Individuals rendered completely legible gain full access to the benefits and resources associated with citizenship and/or whiteness, and others are allowed to be legible only to the degree that they can be exploited. Gaps in census records, contradictions in reported information, and the use of vague categories such as "laborer" exemplify the way the State regards the low-status individuals of the UISC.

The census records themselves are limited in offering insight into ancestry. The State is concerned with the features of loyalty and (potential) citizenship and thus only cares enough to look but a single generation into the past. The issue this poses, with regard to this particular research project, is that most people in the documented subsample of the UISC were born in the United States, as were many of their parents. A birth location in America does not accurately reflect ancestry. For instance, a Texas birthplace for an African American individual does not communicate anything about evolutionary history or adaptations of previous ancestors to particular climates and environments. This complication means that I cannot associate genetic clusters with specific ancestral groups, as American birth locations can include family lineages from a large array of places. For some, it may be possible to track down genealogical information from earlier generations, but it is time consuming work that was not within the scope of this research project.

Preservation issues further present a pressing concern. For many, the cranium and teeth were practically nonexistent. Poor preservation of these elements bleeds over into complications generating nonmetric clusters. Cranial nonmetrics have been studied and employed for much longer than postcranial traits, and are often recommended to supplement use of postcranial nonmetrics (Dunn et al., 2020; Schmidt et al., 2011; Winburn et al., 2022). The lack of intact crania and dentition resulted in a number of individuals being excluded from nonmetric cluster analysis, as the level of imputation of these values would render the information unreliable. Consequently, the sample size used for cluster analysis was greatly reduced from the near 200 individuals with associated documentation. Small sample size reduces the power associated with statistical testing and lessens confidence in results and subsequent interpretations.

Methodologically, one must consider the impact of the osteological paradox, particularly when examining evidence of metabolic stress. The osteological paradox argues that osteologically "healthy" individuals (i.e., lacking evidence of stress) may have in fact been those least suited to cope with significant stressors and perished prior to developing bone lesions (Wood et al., 1992). Those with osteological evidence of stress were strong enough to recover from the severe stressor event, making them, paradoxically, healthier despite skeletal appearances (Roberts, 2013). To apply the concept of the osteological paradox to this particular context, I return to the discussion of metabolic stress in Section 6.4. Prevalence of PH and PR are generally equivalent to what is seen in other contemporaneous populations, but it is difficult to know whether to attribute this to lack of frailty (surviving long enough to develop bone lesions), hidden heterogeneity (persons dying prior to development of lesions and therefore appearing "healthy"), or some degree of combination between the two. This limitation does not affect the validity of results when testing relationships between PH and PR to notch volume. If death occurred too rapidly to develop PH or PR, then it is unlikely that the specific metabolic stressor would be able to affect the intercondylar notch without affecting other elements. Selective mortality is another concern, but a familiar one in bioarchaeological contexts. It refers to the way in which mortuary context only represents people at the time of their death, rendering it impossible to see the entire age cohort and all its variation together. Selective mortality is not the only factor that might influence interpretations of results. The UISC is a skewed sample not entirely representative of the larger Santa Clara Valley population (Agarwal, 2016: 134; DeWitte and Stojanowski, 2015). Consequently, osteological data must be interpreted carefully within these parameters.

Other concerns regarding the methods used include challenges to quantifying notch volume. In creating the 3D model of the intercondylar notch volume, I essentially filled the volume with digital clay, removed it from the femur mesh, and found the isolated volume of the notch mold. Although I performed three repeated passes and used the average to represent the notch volume, each time I did have to manually make value judgements on the notch parameters. The average value was used to limit human error, but until future work fully automates this process, this is a limitation with which I need to contend. The full computerization of these methods has continued to present a significant challenge to myself and others with whom I have attempted to collaborate but may be actualized through the publication and dissemination of these methods. Some researchers may also critique the use of long bone midshaft diameters as characterizations of robusticity and diaphysis shape, as cross sectional-imagery is more accurate, but I deliberately chose to use noninvasive, accessible methods. The "collecting" of individuals too destitute or isolated to afford interment costs is already an ethically concerning practice, and methods should be well thought out to prevent further harm. The exploitation of a marginalized group, even after death, is a form of structural violence, particularly because they were not able to give consent to having their bodies donated to science. Moreover, preservation is a challenge because students practiced medical procedures on the remains, and I do not wish to compound that issue for future researchers. Finally, the use of external measures is a globally accessible method that even those in the field, or those without access to expensive technology, can employ.

Given the morally duplicitous origins of the UISC, all methods should be employed carefully so as to avoid invasion and destruction. Considering this stance, it is worth discussing how studying and publishing could also become harmful. While physical destruction is more obviously a form of invasion, curation and study can become voyeuristic, too. The collection itself is curated well, with new boxes, labeling system, and a room dedicated to this collection alone. Research access is limited in that scholars seeking to study the collection do need to submit a request form detailing the research question, goal(s), and methods to be employed which are then vetted by the State Archaeologist. However, tour groups do visit the collection, and for many, this is the first time they have seen human remains. Previous studies of the UISC occasionally enter the realm of the experimental, with Post-its from failed degreasing trials still adhered to a number of boxes. These colored flags are a testament to the ways in which an almost-forgotten skeletal collection becomes an “appropriate” substitute for experiments that could work equally well using pig bones. A lack of funding contributes to the depersonalization of those in the UISC. The Office of the State Archaeologist has applied repeatedly for funding to dedicate time and effort purely to 3D scan, document, and organize associated documentation. Part of this undertaking would also involve attempting to locate living relatives. However, until this funding manifests, information about the UISC is largely gleaned from visiting scholars who bring along their own funding. From the perspective of the holding institution, the more scholars allowed to engage with the collection, the more information that can be learned about these individuals without needing to secure outside financial commitments. Consequently, experiments on the remains do occur in some capacity.

Part of the solution is to get more researchers interested in the UISC so that the Office of the State Archaeologist can be more selective in who gains access. Additionally, genealogical work to identify living descendants necessarily must be part of the next phases of research concerning the UISC. We can honor the stolen dignity from these individuals by engaging family members in the questions asked/investigated, methods used, and even interment depending on familial wishes. Publications, to prevent legacies of Othering, must: (1) be transparent about the provenience of these remains, (2) engage a structural violence perspective, and (3) be clear about the future of engagement with this collection. It should be a goal of all researchers for these remains to find themselves again with family, even if it means we need to shift our research focus. Moreover, the good done by the publications and research itself must outweigh the harm of maintaining the collection. In this case, I justify this research through its potential to benefit living humans through its impact on physical therapy programs, understanding of injury, and reconceptualization of race within the field of biomedicine. The intentions of this research are in stark contrast to degreasing experimentation, which I argue is more appropriately carried out on remains who voluntarily willed their bodies to science, or animal remains. The reflexivity exhibited here, where researchers critically examine their own role in postmortem structural violence, is crucial in all engagement with collections such as the UISC.

Chapter 7: Conclusions and Future Research Directions

This chapter will begin with a return to the theory that undergirds the interpretations and structure of this dissertation, and that allows the bioarchaeological data to be placed within the appropriate biocultural context. The theoretical conversation in the ensuing paragraphs is meant to highlight the entanglement of history, racialization, capitalism, and biopower to produce the lived worlds of the individuals within the UISC. Following this, I will conclude this dissertation with an enumerated list of the most important findings from this research, as well as an idea of the path forward from here.

7.1 THE STATE, BIOPOWER, AND RACIALIZATION

According to Cedric Robinson (2000: 215), "The white man's principal need is not a home but a satisfied and exploitable people to develop the resources of the country." Western powers accomplish (the use of present tense here is deliberate), through endeavors of colonial occupation, the uprooting of traditional behaviors and modes of governance and rearticulation of social relations (Mbembe, 2003). From these often-violent exploits originated the transatlantic slave trade, a major influence informing historical and modern race relations in the United States. From the perspective of Western colonial powers, the enslavement of black Africans was justified by the Great Chain of Being and through biblical narratives. In the case of the former, black Africans were purported to be 'not far removed from apes' (i.e., inhuman) and in the case of the latter, the Curse of Ham was invoked to portray this group as 'man made degenerate by sin' (Wynter, 2003: 302). Strangely enough, the story of Ham never references blackness, yet it was common knowledge in the antebellum American South that the "mark" borne by Canaan was dark skin (Goldenberg, 2003). The confluence of these powerful narratives made it possible for whites to construct a worldview that saw enslavement as an extension of intentions handed down by nature and deity.

The condition of enslavement resulted in what Mbembe (2003: 21) refers to as a "triple loss" in which individuals were removed from their homes, prevented access to bodily autonomy, and forced into social death. Christina Sharpe (2016) offers the image of "the wake" to understand how enslavement is not a past yet in the past, and which has ripples of influence on black individuals around the globe and throughout time. One of its modern ripples is what Du Bois (2007 [1903]) refers to as the "color line." This line divides those who produce knowledge, namely white Westerners, from "objects of knowledge," or non-white groups (Maldonado-Torres, 2019). The system of slavery structured distribution of resources in accordance with this color line, handing black individuals cards of displacement, disenfranchisement, and experiences of violence, while white individuals granted themselves property and ownership of labor (Escobar, 2016). Consequentially, white individuals were poised for capital accumulation and subsequently, greater power, while black individuals were placed far behind a "fair" starting line.

This is why social justice rooted in an equality-centered mindset will never function; we do not all start from the same point. As Fanon (1968: 40) so poignantly puts it, "The cause is the consequence; you are rich because you are white, you are white because you are rich." What bioarchaeologists must glean from this framing is that “richness” is not necessarily linked to a monetary measure. Even poor whites are imbued with cultural capital in being familiar with, able to more easily navigate, and given deference in institutions within the “legitimate culture” of a society (Bourdieu, 1984). Thus, using socioeconomic status or labor as a variable alone does not accurately capture an individual’s/group’s life experiences or place in society. Put another way, not all groups of the same socioeconomic class will experience the world in the same way. While race is not a biological reality, its social construction and lengthy history have entrenched it to such a degree that it must be considered to properly explain osteological patterns.

It would be reductionist to assume that the color line is maintained by the populace of society alone. The State plays an active role in constructing race relations and ensuring the stability of the status quo. The State employs what Scott (1999: 19) calls immanent power, which is already embedded in a particular tactic of the State and is not outwardly pronounced but informs policy and programs. Immanent power is exerted through control of groups’ behaviors and masking motives through narrative. Both methods, which will be explained subsequently, produce Sojoyner’s (2016) “enclosures” by limiting social mobility of non-whites, and stabilize racial democracy. According to Sojoyner (2016), a racial democracy refers to knowledge produced around phenotype; when you inhabit a physiology, you are already part of a knowledge regime.

One way that the State controls the behaviors of those within its realm is through legislation. For instance, historical rape laws in the U.S. rendered the rape of white women by black men a capital offense while at the same time assuming rape of black women was an inevitable, almost necessary, component of the enslavement condition (Hartman, 1997). In the post-Reconstruction era, criminalization of blackness still fulfilled the desire to render these bodies docile but took on the fervor of a nation no longer able to meet its labor demands (Escobar, 2016). Education, which had previously been denied to those enslaved, was now available in the form of textbooks that imparted practical advice on conduct. Inside, freed individuals would find "a series of imperatives – be industrious, economical, useful, productive, chaste, kind, respectful to former masters, good Christians, and dutiful citizens" (Hartman, 1997: 129). The printing of these primers on how to be a "good" free person illustrates white fear of the potential upending of the racial democracy upon which the country was built.

As a secondary measure, welfare reliance was also criminalized. Despite the clear way in which black individuals were forced into positions of dependency via enslavement by whites in power, this now became the very argument for their exclusion from citizenship (Escobar, 2016). Whites were so discomforted by the idea of black freedom, that they constructed legislation, such as vagrancy laws, that would funnel them into prisons, where slavery was still legal as a mode of punishment. Criminalization of blackness served a twofold purpose: (1) it contributed a solution to the search for cheap labor, and (2) it rendered black bodies back into a state with which whites were familiar and comfortable: bondage. Vagrancy arrests were used to indicate the condition of black laziness and construct a label of "criminal" which was/is used to justify whose life matters in the eyes of the State (Escobar, 2016).

The State also caters to white discomfort and fear through narrative construction. For instance, the State assured plantation owners that enslavement was not a condition of pain. In the words of Hartman (1997: 36), “pain isn’t really pain for the enslaved, because of their limited sentience, tendency to forget, and easily consolable grief.” It is only a strong narrative such as this, coming from and maintained by a hegemonic power, that could render normal bodies beaten and shackled, children separated from parents, lives shortened, and autonomy lost. Often, the rosy portrayals of State governance are not distributed transparently as propaganda, but in documents published by the government it is possible to glean clear intentionality. Consider, for example, the U.S. Armed Forces Counterinsurgency Manual (2006). Counterinsurgency tactics are about using military strategy to pacify, to render legible by armed forces the diverse complexity of local forms of being (Scott, 1999). This manual plainly states that “population control includes determining who lives in an area and what they do…Establishing control normally begins with conducting a census and issuing identification cards” (Department of the Army, 2006: 5-21). Is this not how our own government exerted/exerts biopolitical power on American soil? The manual condemns insurgent regimes for the use of narratives to perpetuate ideologies that legitimate their own power but refuses to acknowledge our State’s use of the same tactic. In this publication, strategies for controlling a hostile populace are laid bare, and we see there is no fundamental difference in structure to our home country. Thus forms the basis to Vargas’ (2018: 76) claim that the privileged and the disenfranchised exist on the same spectrum of oppression extending from the State.

The purpose of the preceding discussion is to recapitulate the truth that labor, socioeconomic status, health, and race cannot be properly understood apart from the variety of ways the State uses biopower to determine who matters. What, then, does this mean for biological anthropologists and this dissertation? First, it means that we must think about race not just as a culturally constructed category, but one that may mean something different on a national level than a local level. Race is weaponized by the privileged group(s), but as this dissertation has discussed, categories can expand and contract depending on perceived threats to this power. If I were to try to understand whiteness in Santa Clara Valley using national sentiments at the time, I would be operating under the faulty assumption that groups such as the Irish were not included in this label. In short, context matters. Second, because the United States is a capitalistic nation, power is almost always synonymous with capital accumulation (i.e., profit). The transition from slavery to the carceral state has been about control, yes, but also about the need for whites to have groups to exploit in aspiration of wealth. As summarized by Hartman (1997: 119), "it is evident that liberty, property, and whiteness were inextricably linked" in the pursuit of forming and managing laboring classes. Cheap labor translates into monetary reward, which begets resource access, translating then into health and stability. Combined with cultural capital, this is the recipe for centuries of a maintained racialized-social hierarchy founded on erroneous conceptualizations of human variability. It is within this convoluted social order that my research exists, and its findings given meaning.

7.2 PRIMARY FINDINGS OF THIS RESEARCH

I present here an enumerated list of the most important conclusions from this years-long research project. They do not exist isolated from the previous discussion of the State, biopower, and racialization, but for the most case, are products of these conditions.

1. **Notch width index and notch volume are not redundant measures.**

In the initial stages of this project, there was some concern that finding the volume of the intercondylar notch was an excessive extra step because it may provide the same results as NWI. If this were the case, we would expect that running the same tests with NWI and then notch volume would reveal the same (non)significant relationships. The results of this research indicate that this is not the case. Notch volume and NWI have different relationships with a number of covariates discussed in this study. I argue that the reason for this discrepancy is that notch width characterizes this locus only from lateral measurements, while the volume simultaneously incorporates variability in additional dimensions. Notch volume is, therefore, a variable worth examining and including in future research.

The importance of this finding lies in its ability to capture variation more accurately. In much the same way that a monolithic category of “white” or “black” flattens ethnic and cultural variation and prevents us from correctly understanding lived experiences, the use of two-dimensional measurements at a joint with a diversity of uses also hides aspects of dissimilarity. I use the results of this dissertation to argue that three-dimensional modeling does garner us a significant step towards being able to quantify variation at this locus with greater precision, but more importantly, may reveal relationships to variables that were not apparent before. This can allow for a greater understanding of how social and environmental contexts shape morphological outcomes at this joint.

2. **Metabolic stress has a positive correlation with notch volume.**

While PR presence has no impact on notch volume, PH presence is significantly associated with larger notch volume. There are two main interpretations of this finding. First, though both conditions are considered non-specific stress indicators, they may reflect different kinds of stress. Perhaps PH reflects a category of stress that also affects the intercondylar notch, while PR does not. The second interpretation is related to the first in that it still hinges on distinct etiological pathways for PH and PR. However, this interpretation centers the concept of survivorship. Potentially, skeletal evidence of PH is indicative of greater overall health even in the face of metabolic stress, and it is this health that conveys protection against notch stenosis. However, for survivorship of PH and *not* PR to be related to intercondylar notch volume, there must be a hidden distinction in causation or survivorship pathways for this result to make sense.

3. **Notch volume is not linked to femoral robusticity or shaft shape.**

Perhaps paradoxically so, the only long bone measure with any meaningful link to notch volume was humeral robusticity index. This was an unexpected result, given that the notch is located in a weight-bearing bone, of which the humerus is not. However, the subsequent interpretation of this relationship to HRI and not FRI suggests that movement type, in contrast to general mobility level and intensity of loading stress, has a greater impact on notch volume. Humeral robusticity is more linked to specialization in activity and lends weight to the interpretation that notch volume is more reflective of movement patterns than labor level. This suggests that two individuals laboring at the same general level of intensity can develop different intercondylar notch volumes depending on the type of work being done and directionality of movement (e.g., unilateral vs. multidirectional).

Moreover, this specific finding presents an interstitial space for conversations of structural violence in relation to injury risk. It is well recognized that the lowest socioeconomic groups are the most marginalized in terms of job opportunity, and often this group is relegated to the most dangerous, difficult sectors. Since low socioeconomic status individuals are all distanced from resource access, some may argue that it is difficult to extrapolate racialized trends among the indigent. However, this finding is evidence that biomechanical and kinesiological studies that can qualify labor movement types/directionality offer another avenue for examining life outcomes. Even if the destitute of all races worked in the most demanding positions, certain races may have been at greater risk for ACL/knee injury based on the *type* of labor sectors into which they were shunted. In other words, even among an economically homogenous category of people, structural violence can be discussed through the framing of injury risk. This is a possible avenue for future collaboration and investigation.

4. **Notch volume scales with body size.**

Notch volume seems to scale with body size. Two variable relationships suggest the strength of this association. First, there is a significant relationship between notch volume and sex. In our species, males tend to be larger than females (sexual dimorphism), and this is true for intercondylar notch volume as well. Second, notch volume is strongly associated with stature, which indicates that intercondylar notch volume seems to scale with increasing body size. Stature is the more reliable variable for which to control as it is scalar, while sex is coded as a binary variable. Sex also has some osteological concerns, such as the general acceptance by researchers that sex exists as a gradient, but continuing to maintain ordinal recording trends. Since NWI, by its ratio nature, inherently controls for body size, there is an added step of needing to control for stature when examining intercondylar notch volume. However, with social science statistical packages like SPSS and R, this is not a difficult process, and as Conclusion #1 indicates, the use of volume is likely to generate more accurate results.

5. **Genetics do not have a significant relationship with notch volume.**

This is the most significant conclusion, and the one that gives this dissertation meaning. The foundation of this project is a critique of the way in which biomedicine lauds genetics as the primary determinant of biological outcomes. In searching for risk factors for a stenotic intercondylar notch, clinicians reify race as a biological concept. I argue that based on extensive literature review on the intercondylar notch, that there is a dearth of testing of the hypothesis that genetics heavily influence the size of the intercondylar notch. It was a possibility that the testing performed within this project would, in fact, prove this assumption correct, but this was not the case. There was absolutely no evidence that genetics (represented by nonmetric trait cluster groups) or assigned racial categories had any notable link to notch volume. Additional testing should be performed on other larger populations to strengthen the validity of results. If this result is upheld through further rigorous testing, medical professionals should take heed and look beyond genetics for answers about biological outcomes. This finding, combined with Conclusions #2 and #3, strongly advocates for the consideration of life experiences, rather than race or genetics alone, when interpreting injury risk and morphological outcomes at the knee joint. The lack of a strong genetic component also increases the likelihood that preventative programs may be able to widen or maintain notch parameters and decrease injury at this locus.

6. **Osteological results support that the category of whiteness in California and the Santa Clara Valley was enlarged compared to other regions of the United States.**

A number of sources claimed that the West coast openly included Irish and German immigrants into the fold of whiteness, unlike much of the rest of the country, but it was possible that this information was sourced from romanticized propaganda of the region. However, osteological results validate these claims. A large proportion of the UISC was categorized as white (both native- and foreign-born) and nonmetric trait frequencies were utilized to group these individuals into genetically similar groups. Although there are limitations to the data that prevent matching clusters with discrete ethnicities, these groups should reflect regional ancestry. Put another way, there were 5 clear nonmetric groups, all of which were made up of people recognized as white in the primary documentation. There were no clear distinctions between the clusters with regard to PH, PR, notch volume, NWI, stature, or any midshaft measures. Therefore, it is clear that regardless of what "flavor" of white people are represented, they shared similar life experiences of labor, resource access, and opportunities (or lack thereof, given low socioeconomic standing). Therefore, the Othering of certain nationalities/ethnicities not yet considered white in other regions of the country does not seem to be perpetuated in this population from the Santa Clara Valley.

7.3 FUTURE RESEARCH DIRECTIONS AND INJURY PREVENTION

Future directions for this research are abundant. First, the sample size must be expanded, particularly with regard to ancestry. The documented UISC sample is predominantly white, and the strength of the nonmetric clustering method cannot be fully assessed until it is tested on a sample population with higher genetic diversity. More females must be included in the future, as the UISC is also primarily male, so it is difficult to determine if males and females are experiencing the same covariate relationships with notch volume. I also would like to broaden the temporal scope of this research. Extension further back in time may not be easily achieved, as associated documentation is necessary for this project and preservation of older documents becomes less likely. However, even examining populations that are more recent can give a sense of how the intercondylar notch volume has changed over time (i.e., is there trend towards smaller notches?) and contextualize an explanation for this pattern.

Second, if possible, collaboration with other researchers should seek to improve the methods of calculating the intercondylar notch volume. The creation and solidification of 3D mesh models is fully computerized and is not subject to human error. However, the modeling of the intercondylar notch is not wholly unbiased. The user must manually detect notch parameters in each manipulation and it is impossible to delineate the same parameters every time. Literature on 3D mesh manipulation suggests it may be possible to have a computer program use edge detection to calculate the best fit notch parameters and use the shooting of hypothetical rays to find the best fit curvature of the unenclosed posterior region of the notch. As of yet, it has been a challenge to bring this vision to light, but publication of these methods may reach a scholar that will be able to help. The realization of these changes to the 3D method would greatly reduce, perhaps almost eliminate, the amount of human error involved in calculations of the volume.

Another avenue of possibility includes filling in gaps in primary documentation. Much of the information included in this research project reflects census records, draft cards, and death certificates. The issue with this type of documentation is that there is a great deal of time typically passing between each “blip” on the record. An additional challenge is that persons of color experience a relative lack of specific and reliable information on these records. It is worth the time to put effort into genealogical work tracking down additional primary documentation to construct a more accurate picture of individuals’ lived experiences. This is one aspect of future research directions in which it might be easiest to integrate undergraduate student involvement. This would produce a better understanding of labor history, movement between domiciles, and ancestral lineage, all of which are important to accurately contextualizing osteological data.

Finally, after the meaningful notch volume patterns revealed in this dissertation are better understood, and the scope of this research expanded and more rigorously tested, applications can and should be made to living populations. This portion will necessarily be collaborative. Physical therapists will likely be the most efficient collaborators, as they are best qualified to help design, implement, and evaluate a risk mitigation program among living patients. If future research upholds the initial conclusion that genetics do not play a large role in the volume of the intercondylar notch and bolsters the claim that movement type does impact notch shape, then it should be possible to alter the parameters of the notch over time. Programs that would aid in maintaining notch size or even increasing it could be crucial to the prevention of debilitating injuries to at-risk groups, particularly those who have already experienced reconstruction of the ACL and/or previous injury. The fact that genetics play a relatively minor role (as stature is somewhat heritable) in intercondylar notch development engenders hope. It helps destabilize the popular notion of race as a biological reality and suggests that the significant number of ACL injuries reported each year are not a problem without a solution. Though historical bioarchaeology focuses on past populations, there is a real possibility that research such as this can solve modern issues of the body.

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