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Social Inequality and the Body: Diet, activity, and health differences in a prehistoric Muisca population (Sabana de Bogotá, Colombia, AD 1000-1400)

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Social Inequality and the Body: Diet, activity, and health differences in a prehistoric Muisca population (Sabana de Bogotá, Colombia, AD 1000-1400)

By

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Professor Todd Dawson

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Abstract

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Doctor of Philosophy in Anthropology

University of California, Berkeley

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This project uses multiple methods to explore how the biosocial variables of age, sex, and status intersect with social inequalities in a prehistoric Colombian population. The archaeological site of Tibanica in the Sabana de Bogotá, Colombia (AD 1000-1400) is an ideal place to examine the biocultural aspects of intersectionality, as it is a settlement of a complex chiefdom society. Inequality may be tied to age groups, differences between the sexes, or between those who are archaeologically recognized as higher/lower status based on mortuary practices. This project studies three loci where identities and inequality may be expressed and evidenced in the body: food consumption patterns, physical labor, and skeletal health. Human skeletons present the opportunity to study how these variables that are both biologically real and socially constituted, may relate to unequal power access within any society. 199 human skeletons were studied using stable isotope analysis ($\delta^{13}C$, $\delta^{15}N$) of tooth and bone samples (n=199) to reconstruct individual dietary histories, cross-sectional geometry analysis of femur (n=63) and humerus (n=33) bones to study human activity patterns, and bone remodeling in the metacarpal to examine overall bone loss and health (n=75). Dietary and activity data indicate significant differences between women and men over the lifetime, suggesting that different spheres of identity and activities were delineated by sex and age. Stable isotope data show differential access to particular foods, with both sexes consuming significant amounts of maize, but females consumed less maize and more C_3-type foods than males. Cross-sectional geometry data revealed that male work emphasized lower body strength, probably related to agricultural work, while female activities required a strong upper body, likely related to food preparation and childcare activities. Skeletal health data indicate that in older age both women and men lost cortical bone in the hand, but women were more severely affected earlier in life, possibly due to skeletal responses to pregnancy and/or lactation. While historical and archaeological research of the Muisca has focused on the importance of social rank within a hierarchical chiefdom society, this dissertation suggests that a very salient aspect of everyday experience for the Muisca may have begun with social difference of another kind: between the sexes. These results demonstrate the capacity for bioarchaeological studies to provide unique data that can reveal complex social relationships that may not be observed through other lines of evidence, challenging assumptions about ancient peoples, and directing us to new lines of inquiry.

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Chapter 1: Introduction

This dissertation project examines the intersections of multiple biosocial variables (age, sex, status) with the quotidian experiences of diet and activity, and their cumulative effects on bone health in a pre-Columbian population from northern South America. Two of the most fundamental aspects of everyday human life are eating and working, and what a person can do with their body and feed their body are complex products of the life circumstances of each individual within a particular cultural context. Throughout human history the spheres of food and activity have been the most central structuring practices of daily life, and were often interconnected as work activities are commonly related to the procurement or preparation of food for most people. These areas are also deeply, locally contextualized, such that food and labor activities form central pinnacles of cultural practice and identity. In addition to these practices being culturally-specific they are also deeply personal and reflect layered and intersecting aspects of individual social identity, and political and economic power. This dissertation research utilized multiple bioarchaeological methods to examine how difference is expressed and embodied, particularly focusing on how inequality is related to the biosocial variables of sex and age within a Muisca population. Human skeletal remains from 199 individuals excavated from the Tibanica archaeological site from the Sabana de Bogotá, Colombia were examined for evidence of diet, activity, and skeletal health.

Social difference is often marked in particular ways and maintained over periods of time through daily practices, such as social rank being marked by the acquisition, usage and display of items associated with 'wealth.' Most societies are not egalitarian, with groups marked by difference through various identifiers that those within the group recognize and reify through cultural practices. For example, gender-divisions of labor may be common to one society and define the types of activities that men, women, or those of another gender category can perform, while other communities may not delineate activities along the lines of gender but perhaps by another variable (such as age, status, familial background or kinship group, etc.). Access to food is another domain where inequality may be expressed and ultimately evidenced in the human body. Food practices are deeply intertwined with social identity and power, for example high status individuals may have privileged access to particular foods that others do not, or we may see age- or sex-related patterns in diet indicating other social divisions that are marked by consumption practices.

When the Spanish arrived in the Americas they documented numerous cultural groups that they encountered and attempted to interpret and understand through their own European world view. The documentary record that they left is often seen as compelling evidence of life at the time of contact, and has been repeatedly used as a road map and a lens through which interpretations of ancient cultures have been defined and presented. The Muisca of northern South America (from the Eastern Cordillera of the Andean mountain range in present-day Colombia, around the capital of Bogotá) have been particularly affected by the historical writings that were recorded in the 16th and 17th centuries. These documents have often been used as the definitive record of how the Muisca were, framing them as a "classic chiefdom" society where hierarchical structures of social rank and power dominated the socio-political-economic landscape and

structured social life. Therefore, the Muisca are an ideal population to study the effects of embodied inequality across multiple axes of social identity.

The principle research questions posed here are centered on understanding the complex interactions of social life on the everyday practices of Muisca people. Was social status a prime driver of social difference within Muisca culture? Were other aspects of social experience such as sex and/or age also axes of social difference or social coherence? This project begins with the central belief that aspects of daily life such as eating and working are spheres of activity that are deeply intertwined with a person's identities within their community. What we eat and what we do with our bodies are a reflection of numerous aspects of our place within a larger social, political, economic, and ideological environment. Therefore, these quotidian experiences are a productive avenue of research as they can reveal deeper social relationships that other forms of evidence may obscure.

Embodiment and Inequality

This research is predicated on the belief that the human body is shaped by both biological and cultural experiences unique to each person. In this way the person is seen through a biocultural perspective, giving weight to both biological and cultural variables as influencing the physiological and psychological ways of being in the world. The human skeleton is a dynamic and plastic bodily tissue that responds to both internal (genetic, physiological) and external (diet, activity) stimuli, creating a structure that is both durable but also capable of change in response to shifting biological and cultural conditions over life. The skeleton reflects an accumulation of personal life events which construct the shape that is deposited into the archaeological record at death, therefore the skeleton acts as a material that traces its own life-history (Sofaer, 2006). As a bioarchaeologist I find embodiment theory to be a useful framework to focus and ground our understanding of humans as culturally specific biosocial beings. Embodiment theory begins with the recognition that the human body is the instrument through which we understand and come to experience what it means to be alive within the world, with sensory perceptions creating, defining, and delimiting ones' self, relative to others (Merleau-Ponty, 2002 [1945]). A body becomes socially identified as part of a larger social group through bodily habit and action (Mauss, 1973[1935]). Our complex ways of being are often normalized, naturalized, learned and taken for granted through an education of the body (Mauss, 1973[1935]).

Pierre Bourdieu builds on the ideas that Mauss presents of a body that 'knows' with his development of the terms *habitus* and *hexis* (Bourdieu, 1977). For Bourdieu, *habitus* is a system of durable dispositions that are internalized and direct one to carry his/herself in a manner appropriate to presented situations (including through embodied practices, or hexis), and these ways of being are rooted in a historical and culturally specific understanding of how one should act and maneuver accordingly (Bourdieu, 1977; Taylor, 1999; Farnell, 2000). Judith Butler discusses some of the strong echoes that Bourdieu's *habitus* (and *hexis*) have with Merleau-Ponty's discussions of a knowledgeable body - how social rules become incorporated into the being (body-subject) and comprise doxa (Butler, 1999). The knowing body is created through participation within a larger social existence, and reflects the experiences of an embodied person navigating the world (including self-knowingness and memory; Butler, 1999).

Bourdieu believes this process, whereby beings become normalized to these socially implicit conformities, occurs through *mimesis* (reproducing a model in action; *The Logic of Practice* Bourdieu, 1977; Butler, 1999). Social actions bring bodies to life in certain ways that then, "reproduce and ritualize those conventions as practices. In this sense, the *habitus* is formed, but it is also *formative*" (Butler, 1999:116). Bourdieu links *habitus* to practice, as it is through the doing and the continual interpretation and reinterpretation of these ways of doing and being that *habitus* becomes realized as the correct ways of being (Bouveresse, 1999; Taylor, 1999). Thus it is through experience and practice that individuals acquire these dispositions and, complexly, it is through the repeated manifestation of these non-articulated ways of doing things that they become normalized and non-discursive. As Butler states, "this *habitus* that the body *is* generated by the tacit normativity that governs the social game in which the embodied subject acts" (Butler, 1999:115). Therefore, *habitus* can motivate certain behaviors that, while they must be acquired through a learning process that includes practice and repetition, feel completely natural, instinctual, and rational (Bouveresse, 1999). The body is formed in *hexis*, through the imitation, repetition and practice of actions such that they become reflexes (Butler, 1999). The body is the site of incorporated history and memory, it is the site of understanding, expression and performance of ritualized actions (Butler, 1999). The body is the place of possibilities for action, which are learned in early life and become incorporated into a person's permanent disposition, influencing their ways of being both physically and mentally so completely and without need for discourse that they are naturalized and removed from most conscious thought and action (Butler, 1999; Farnell, 2000).

In her discussion of Bourdieu's separation of linguistic *habitus* from the social *habitus*, Butler (1999) uses the example of calling one a "girl" from early life onwards. This naming effectively causes the person to be "girled" through time, creating a gendered, embodied being through the socially performative speech acts that shape the individual's experience and practice of a socially inscribed *habitus* (Butler, 1999). Butler's example of calling someone a "girl," a seemingly more mundane linguistic act, is still just as socially important and constitutive of creating an embodied person who will then act accordingly (such as being a gendered girl who acts in a manner appropriate to social expectations of "girl"). As an embodied person who is operating within a larger social existence, we work the *habitus* when we take something that was below consciousness (a previous doxa) and bring it to light. We have the opportunity to either reinforce the doxa through adherence and repetition (orthodoxy) or contest it (heterodoxy; Bourdieu, 1977). The experiencing body can become aware of structural circumstances (bodily *hexis*) and of how the bodily practices and ways of doing become *habitus* in action: our repetition and reinforcement of doxa is the social working of the *habitus*. Butler concludes that the *habitus*, as both formed and forming, in conjunction with the social circumstances that are created by and constitutive of embodied persons, will be performed and acted on through the inextricable linguistic and social forces (Butler, 1999). We can see these forces at work in ourselves and others both in modern and ancient peoples, and we can use archaeological evidence to better understand the complexity of social relationships that constituted human life in the past. The human body (and its skeleton) is dynamic, responding to external and internal forces, being

shaped through biocultural life, and leaving a material record of individual experiences which can then be interpreted through these theoretical frameworks.

The two main research foci of this project (diet and activity) are also well suited for study through bioarchaeological analysis of skeletal remains. The foods we consume are the chemical building blocks for all of our bodily tissues and therefore we are creating and re-creating our body with each meal. Food and drink are deeply meaningful products that are created, consumed and incorporated into our physical being. Michael Dietler notes, "…food is what may be called "embodied material culture": that is, a special kind of material culture created specifically for immediate destruction, but destruction through the transformative process of ingestion into the human body…hence, it has an unusually close relationship to the person and to both the inculcation and the symbolization of concepts of identity" (Dietler, 2007:222). The foods we consume have meanings that intersect with aspects of identity and study of food practices can reveal some of the social relationships that structure daily life. In continuing this line of thinking, and following Bourdieu's ideas of *habitus*, Dietler says the daily actions of eating, being required routine practices, "…serve to inculcate habitus – that is, the set of embodied dispositions that structure action in the world and that unconsciously instantiate perceptions of identity and difference" (Dietler, 2007:222). Therefore, the foods we eat and the act of eating is always occurring within a matrix of culturally-specific and historically situated meaningful practices that are mostly non-discursive but can reveal aspects of social differentiation through their very existence. This same argument can be made for daily labor and activity patterns – the repetitive work that bodies perform are inextricably linked to identity and social differentiation (we don't all work at the same jobs for myriad reasons related to self and our society). Through performance of daily work, we embody these identities which are situated within a larger socio-political field and our adherence or adjustment of these practices may be maintained or change over our lifetimes. Eating and working may then serve as evidence of the deeper relationships that constitute the fabric of any society, and study of these domains may provide new ways to understand the kinds of social difference and inequalities that existed in the past.

Inequality is a central phenomenon within the anthropological study of social processes. Anthropological archaeology grapples to understand and interpret changing social complexity through time and space and investigates how inequality emerges and changes across cultures (Berreman and Zaretsky, 1981; McGuire, 1983; Paynter, 1989; McGuire and Paynter, 1991; Hayden, 2001; Blanton, 2005; Price and Feinman, 2010; Smith, 2012). McGuire broadly defines inequality as "differential access to material and social resources within a society" (1983:93). Archaeological studies of inequality and social complexity have traditionally focused on the material evidence of difference such as analyses of burial treatment, monumental and architectural constructions, settlement patterns, differential access to resources, and comparisons of the quantity and quality of artifacts/ecofacts (Drennan et al., 1991, 2010; Price and Bar-Yosef, 2010). This study will contribute to the anthropological study of inequality through a bioarchaeological analysis of daily life activities in an emergent chiefdom, the Tibanica community. This approach will provide new data for examining how inequality may have been acting along multiple social dimensions and may be evidenced in the human body. In particular, what were the effects of certain forms of inequality on social relationships in emergent complex societies and are these relationships evidenced in the body?

Inequality affects the physical body and may be recorded on the skeleton as traces of differential experiences such as gendered food behaviors, sexual division in labor activities, or differential health outcomes (Cohen and Armelagos, 1984; Brumfiel, 1991; Sofaer Derevenski, 2000; White, 2005; Hollimon, 2011). Inequality may be evidenced through distinct access to and consumption of various foods, such as maize, which has been associated with males or high status individuals in some prehistoric societies in the Americas (Hastorf, 1991; Ubelaker et al., 1995; White, 2005; Cuéllar, 2013; Somerville et al., 2015). Divisions of labor are also inextricably tied to inequality as one's social roles may dictate the type and intensity of work an individual can perform (Murdock and Provost, 1973; Spector, 1983; Brumfiel and Earle, 1987; Brumfiel, 1991; Gero, 1991; Watson and Kennedy, 1991; Hendon, 1996). The biosocial dimensions of inequality focused on for this dissertation project include age, sex, and status, which can operate in an individual's social persona either independently or through intersection and can reveal both complex and subtle variations that may correlate with particular types of inequality (Weber, 1947; Berreman, 1981; McGuire, 1983). In particular, this work will examine two areas of quotidian practices (food consumption and physical labor patterns) as potential areas where inequality may be operating and evidence long-term social processes.

Studies of singular material indicators of inequality can also obscure the nuances of these socio-political-economic relationships and depending on the line of evidence, may also reflect only particular moments, such as mortuary treatment at death, in comparison to longer-term patterns of inequality, such accumulated household refuse (Drennan et al., 2010). The lines of evidence used here reflect the long-term patterns of behavior that may have been structured along particular social divisions of inequality. Food consumption habits are revealed through stable isotopic analysis and reflect the average dietary patterns of many years of eating, and therefore obscure single events (such as occasional feasting). The skeletal development of the femur and humerus bones in response to repeated mechanical stressors reflects the cumulative response of the body in motion, reflecting the repeated actions of labor patterns the individual accumulated from growth into adulthood. These two foci provide insights into the subtle and continuous ways that inequality may be operating through the very quotidian actions of eating and moving. These long-term proxies for repeated behaviors may also confirm or contrast significantly with other archaeological indicators of inequality, which may reflect very different scales of time where social inequalities may be heightened or reduced.

Project Methods and Background

Food Practices and Stable Isotope Analysis

Food – it is a biological necessity and a dynamic material that is often layered with cultural meanings. Anthropologists have recognized the power that food has and the potential for food studies to reveal political, economic, and social relations and meanings (Hastorf and Weismantel, 2007). Control over food production and procurement implies power relations where some people have greater access and some have less, both in terms of economic and political power. The relationships between food and power have been explored both in archaeological and modern contexts (for example numerous edited volumes have been produced, such as "Food and Culture" by Counihan and Van Esterik,

2008, and "Food and Gender, Identity and Power: Food and Nutrition in History and Culture" by Counihan and Kaplan, 2005). Food relations also encompass more than just what is being consumed, but include who is producing which things and why, who has control over particular foods or sources and why, and then who is able to or permitted to eat certain foods and why. These actions are all embedded within systems of power and dynamic social relationships, and therefore food practices can reveal these deeper systems through close study.

Archaeological studies can use preserved food remains to ask and answer questions about past human experiences – food is particularly useful since it is universally required but takes on very specific meanings within cultural settings (Douglas, 1984[1966]). Hastorf and Johannessen state, "By tracking the changing contexts of food use and its stages of production, processing, and consumption, as well as where it is consumed and who consumes it, we can begin to discover past contexts and meanings surrounding food" (Hastorf and Johannessen, 1993:116). Research on food ways can help us understand world views/cosmologies (Malinowski, 1935; Richards, 1951; Sterckx, 2005), identities (Richards, 1951; Holtzman, 2006; Twiss, 2007), times of continuity and times of change (Braudel, 1979; Dietler, 1990), political and economic roles of food (Malinowski, 1935; Mintz, 1985; Weismantel, 1988; Dietler, 1990), the complex social roles of food in public and private, particularly highlighting relations of power (Braudel, 1979; Appadurai, 1981; Mintz, 1985; Dietler, 1990; Sterckx, 2005). Archaeologists have studied evidence of human food ways from botanical remains (Hastorf, 1999), faunal remains (deFrance, 2009; VanDerwarker and Peres, 2010), iconographic representations (Allen, 2002; Cummins, 2002; Soderberg, 2004), pottery and other material remains used for food preparation and serving (Deetz, 1996; Bray, 2003a), and increasingly through chemical analyses of archaeological materials, including human bones and teeth (Lee-Thorp, 2008). Stable isotope analysis of human tissues has proven to be a productive tool for investigating ancient human diets, as isotopic values provide direct evidence of food groups that were repeatedly consumed.

The chemical signatures of the foods we eat are recorded in our bodily tissues and can indicate particular food groups that a person consumed. Stable isotope analysis of skeletal tissues such as bone and teeth provide direct evidence for the diets of individuals (DeNiro, 1985; Schwarcz and Schoeninger, 1991; Ambrose, 1993; Lee-Thorp, 2008). Teeth are a unique skeletal tissue because they form at discrete periods during childhood and adolescence and then do not remodel, therefore serving as a record for different periods of diet during childhood (Ambrose, 1993; Sealy et al., 1995). In contrast, human bone is constantly remodeling itself in response to biomechanical stress, metabolic needs, and in response to damage accumulation (Parfitt, 1979; Frost, 1987, 1990, 2003; Parfitt, 2003). Therefore, bone chemistry reflects the dietary average of approximately the final decade of life (Ambrose, 1993). Stable isotope chemical analysis of both tooth and bone tissues from the same individual allows us to examine how a person's diet changes or remains stable from childhood to adulthood.

Many research projects have used stable isotope analysis to examine ancient human diets (Vogel and van der Merwe, 1977; Lee-Thorp et al., 1989; Schwarcz, 1991; Schoeninger and Moore, 1992; White, 2005), migration of populations (Price et al., 1994, 2002;, Knudson et al., 2005, 2010), marine versus terrestrial ecosystems (Chisholm et al., 1983; Schoeninger and DeNiro, 1984; Schulting and Richards, 2001), and for

paleoenvironmental reconstructions (see the edited volume by Leng, 2006). The majority of archaeological applications have examined questions related to food consumption habits and in more recent years stable isotopic applications have been explicitly used to address larger questions related to social status, gender, and identity.

Each isotope contributes different information to our understandings about an individual's life history. Carbon, nitrogen, and sulfur isotopes provide dietary evidence (Lee-Thorp, 2008) and hydrogen, oxygen, and strontium isotopes are connected to the geographic location of people through the water and food sources that people consumed (White et al., 1998; Ehleringer et al., 2008; Knudson, 2009). Carbon is incorporated into skeletal tissue in both the organic (collagen) and inorganic (as carbonate in the hydroxylapatite) matrices. Nitrogen is incorporated into the protein portion of skeletal tissues (mostly in collagen). These elements are derived from dietary sources so that the tissue reflects the dietary inputs; therefore 'you are what you eat.' Bioarchaeologists are able to exploit this in order to investigate past human dietary practices. This research focuses on carbon (both from collagen and apatite) and nitrogen isotope analyses and applications.

The carbon that is incorporated into skeletal tissues is derived from dietary components. The hydroxylapatite matrix in bones and teeth is the inorganic fraction of these tissues and contains a small amount of apatite carbonate within its structure that can be analyzed for carbon stable isotopes. The apatite carbonate is representative of all the carbon sources in the diet – including plants (those utilizing C3, C_4, and CAM photosynthetic pathways) and terrestrial and aquatic animals (Passey et al., 2005). The apatite carbonate represents the carbon isotope values found in the carbohydrates, fats, and proteins of these consumed source foods (Ambrose, 1993). Type-I collagen is the predominate protein found in the organic fraction of bones and in tooth dentin, providing data for carbon and nitrogen isotopes. An early study by Lee-Thorp et al. (1989) tried to characterize the difference between carbon values in apatite and collagen, which at that time was not as precisely known to reflect different carbon matrices. Work by Ambrose and Norr (1993) and (Tieszen and Fagre (1993) demonstrated that collagen disproportionately represents the carbon that is derived from protein sources in the diet. Therefore, analysis of both the collagen and apatite carbonate for carbon isotope ratios provides the researcher with a wider range of information about the dietary components that would have contributed to those values. For example, since human bone collagen disproportionately represents the protein sources in the diet, collagen carbon can indicate which protein sources are heavily relied on (do you consume browser or grazer terrestrial mammals, do you consume seafood, etc). By comparing the collagen carbon value(s) to the carbonate carbon value(s), researchers can get a better understanding of the variability in human diets.

Nitrogen stable isotope values are derived from the collagen portions of bone and dentin, and these are linked to the protein sources that were consumed. In a well-studied ecosystem, it is possible to identify different animal’s location within the food chain based on their nitrogen isotope data. As an organism rises through the food chain, from primary producers (such as terrestrial plants), to herbivore, to omnivore, and finally to top-level carnivore there is a step-wise increase in nitrogen isotope values. Therefore, carnivores have the highest nitrogen isotope values in terrestrial ecosystems while plants and herbivores consuming those plants have significantly lower isotope values. These

relationships between consumers allow us to use nitrogen isotope data to investigate protein consumption in ancient human populations. However, human food systems are quite diverse, complicating the interpretation of nitrogen isotope data for many human groups in the past and present. Additional issues such as the use of fertilizers, foddering animals on human food scraps, and movement of people (or food resources) across ecosystems all add layers of possible error to interpreting nitrogen isotope data (Bogaard et al., 2007; Szpak, 2014; Swift et al., 2016). Emerging advances in isotopic theory and analysis are emphasizing a multi-isotope approach and inclusion of as many possible sample types as possible so as to try and constrain sources of error.

This dissertation project studied isotopic signatures in a large sample from the Tibanica population (n=199 individuals) and also includes faunal samples recovered from the archaeological site, and modern plant samples grown on a farm near the archaeological site. Since the focus of this research is how a person's sex, age, and status may be variables that influence food practices, a large sample of adult human skeletal remains was needed in order to capture as many of those variables as possible. This project is also interested in how practices may change or remain stable over the lifetime. Studying both a bone and a tooth sample from each adult individual provides two snapshots of dietary history per person: the average early diet (childhood diet recorded between ages 5-15) and the average later diet from the decade prior to death.

Physical Activity and Cross-Sectional Geometry of Long Bones

Patterns of daily labor are another sphere of activity that are deeply connected to a person's identities within their community and may reflect unequal power relationships. For example, work may be divided by gender, age, or status, and consequently work patterns may also change over the lifetime. Children may have chores and responsibilities that change as they grow into adolescence and then adulthood, and these activities may also intersect with aspects of individual gender identity (male/female/other gender) or social status (high/low). Importantly, bioarchaeologists have noted that the things people do with their bodies on a daily basis leave lasting traces on the skeleton as evidence of the kinds of work they habitually performed (Krølner and Toft, 1983; Pearson and Lieberman, 2004; LeBlanc et al., 2007; Ruff, 2008). To test the research questions of how labor practices may differ in this Muisca community across multiple social groups and potentially reflect particular forms of social organization, this project analyzed femur (n=63) and humerus (n=33) bones using cross-sectional geometry analysis.

What we do with our bodies causes morphological changes that can be observed in the skeleton (Martin, 2003; Ruff, 2005; Robling et al., 2006; Ruff et al., 2006). The morphological features of any skeletal element are a complex reflection of numerous factors such as genetics and activity patterns, and there are multiple ways that biological anthropologists have approached morphological studies of the skeleton to investigate ancient activity. The skeleton of a person who labors daily in agricultural fields will likely reflect the physically demanding nature of that labor while a person who does fine craft work may show a dramatically different morphology reflecting those activities. Bioarchaeological studies have used various methods to study the effects of physical labor on skeletal morphology, with three main areas of investigation: entheseal changes (also known as musculo-skeletal markers), pathological changes to the skeleton (such as degenerative joint disease), and cross-sectional geometric properties of long bones.

Entheseal markers are discrete areas on bone where muscles exert force and cause subsequent changes to the underlying skeletal structure. These boney markers are viewed as indicators of muscle groups that are repeatedly used over time and therefore are seen as a direct reflection of active engagement of those tissues as they exert force on the underlying bone, causing remodeling changes to build up at those specific attachment sites (Villotte et al., 2010; Henderson, 2013; Henderson et al., 2013; Niinimäki and Baiges Sotos, 2013; Villotte and Knüsel, 2013). Numerous studies of prehistoric populations from around the world are now utilizing this method to ask questions about activity and movement, particularly between specific groups within the same population (Villotte et al., 2010; Campanacho and Santos, 2013; Cardoso and Henderson, 2013; Villotte and Knüsel, 2013; Santana-Cabrera et al., 2015; Schrader, 2015).

Degenerative joint disease is often studied as an indicator of particularly stressful activity on specific joint groups in the skeleton (Klaus et al., 2009; Watkins, 2012; Klaus, 2014). In these cases, pathological changes to bone are viewed as the result of repeated wear on the joint causing damage over time to the bone surface and structure, which results in morphological changes that have been linked to conditions such as osteoarthritis. These pathological changes are observed in most populations to some extent as natural wear-and-tear on joints with aging often leads to skeletal degeneration, however differential examination of this between and within populations allow for nuanced questions to be posed about the types of skeletal stress experienced and by whom (Ortner, 1968; Jurmain, 1977; Verano, 1997a; Ubelaker and Newson, 2002; Klaus et al., 2009).

The method this dissertation uses to examine activity practices is cross-sectional geometry analysis of long bones. Cross-sectional geometry (CSG) examines a transverse section of bone and uses a number of quantitative measurements to assess bone quantity and aspects of bone strength. CSG analysis is based on engineering principles such as beam theory, where a long bone shaft can be examined for performance under loading conditions and measured in reaction to theoretical bending, torsional, compression, and other forces (Huiskes, 1982; Ruff, 2005, 2008). Changes to the amount of bone in cross-section and its distribution about the shaft (size and shape features) are related to the types of forces that bone has been exposed to over the lifetime (Ruff and Hayes, 1983a; b; Ruff et al., 1984). Mechanical loading stimulates cortical bone modeling and remodeling (Parfitt, 1979; Frost, 1987, 1990, 2003; Parfitt, 2003) and as a result the cross-sectional properties of a long bone reflect adaptation to habitual mechanical loads. Non-invasive CT (computed tomography) images were taken at a medical facility in Bogotá, Colombia of femurs and humerii from Tibanica adults across multiple age and sex groups. These bones were selected for analysis to compare upper and lower body strength and robusticity, which are a product of skeletal and muscle use in those limbs.

Cross-sectional geometry has been used to study changes to femoral, tibial, and humeral size and shape within and across populations. Measurements of total bone quantity (total subperiosteal area, cortical area, medullary area, % cortical area), shape (Ix/Iy; Imax/Imin), and strength (J) are the cross-sectional properties commonly studied to investigate ancient activity patterns. For example, femoral cross-sectional shape is thought to relate to anterior-posterior (A-P) or medio-lateral (M-L) movements, where high Imax/Imin ratios (greater than 1.0) indicate higher levels of walking or traversing rugged terrain (A-P loaded legs), while ratios less than 1.0 suggest activities that are more

M-L oriented. Many studies have examined changes to the leg bones in relationship to changes with our species and evolutionary adaptations, particularly noting the effects of increased sedentism (Ruff et al., 1993; Trinkaus and Churchill, 1999; Trinkaus and Ruff, 1999; Shaw and Stock, 2013). Other studies have focused on how skeletal morphology is a product of activities associated with different subsistence strategies (for example, comparing hunter-gatherer populations, horticulturalists, and sedentary agriculturalists) in order to study large-scale changes to the human body that occur with these dramatic lifestyle shifts (Ruff and Hayes, 1983a; b; Ruff et al., 1984; Bridges, 1989; Stock and Pfeiffer, 2004; Wescott and Cunningham, 2006; Sparacello and Marchi, 2008; Stock et al., 2011). Other bioarchaeological studies are interested in how cross-sectional bone properties may indicate divisions of labor that are marked along particular social lines such as gendered labor patterns (Maggiano et al., 2008; Ogilvie and Hilton, 2011). This dissertation uses common CSG measures to study how activity patterns may reflect differences in labor between males and females and across different age groups. Do we see any patterns of work emerge within or between subsections of this population from Tibanica or is labor relatively similar for all individuals in this community?

Skeletal Health and Metacarpal Radiogrammetry

The development and maintenance of a healthy skeleton is a function of numerous interacting factors including genetics, diet and nutrition, activity, hormones, and more. Skeletal health can be assessed in many ways and one of these is through measurement of cortical bone quantity at various skeletal sites such as the metacarpal, the rib, or a long bone. One of the motivations for studying bone health in ancient populations is to better understand skeletal health in modern populations. Osteoporosis (bone loss leading to increased risk of skeletal fracture) is an increasingly prevalent health condition effecting hundreds of millions of people around the world each year (Johnell and Kanis, 2006; Looker and Frenk, 2015). Modern clinical studies have documented that in many populations women are at a greater risk of bone loss than males and that this bone loss often occurs earlier in life for women (Sowers, 1996; Rosen, 2002; Stini, 2003; Looker and Frenk, 2015). Why do humans lose bone and what factors lead to increased risk of osteoporosis? Studying ancient populations can provide important information about the history of this disease and its existence and prevalence in human history across time and space.

Much of the work on bone maintenance and loss in past populations has emphasized European groups, likely because osteoporosis rates are particularly high in women from Western nations (Mays, 1996, 2000, 2001; Beauchesne and Agarwal, 2014). The modern clinical model suggests that Western women (particularly Caucasians and some Asian groups) are at the highest risk of developing osteoporosis and fracturing a bone (Nelson and Villa, 2003). Two of the leading drivers of bone loss are thought to be hormones and natural aging processes, with females especially affected after menopause due to dramatic changes in their hormonal state (Agarwal and Stuart-Macadam, 2003; Agarwal and Beauchesne, 2011). Far less attention has been given to Native American populations (both modern and ancient), however this disease is increasingly affecting populations that are not Western females, and studies show osteoporosis and osteopenia on the rise in many countries (Mautalen and Pumarino, 1997; Morales-Torres et al., 2004; Handa et al., 2008). The emergence of this health crisis in other populations suggest that

genetics are not the sole factor leading to the development of this disease and that many lifestyle factors play a significant role in mediating skeletal health (Londono et al., 2013).

This dissertation will provide novel data on skeletal health in a South American population and will aid in expanding our understanding of bone maintenance and loss in a non-Western pre-Columbian society with very different lifestyles from the populations that have traditionally been studied. Radiographs (x-ray images) of the second metacarpal were taken from 75 individuals from the Tibanica archaeological community. Cortical bone area is measured (in addition to total area and medullary area) to study how bone develops, is maintained, and then may be lost in conjunction with the biosocial variables of a person's sex and age. Analysis of other archaeological populations have shown differing patterns of bone loss tied to sex and age, with some groups fitting the modern models while others do not (Agarwal and Grynpas, 1996; Mays, 1996; Glencross and Agarwal, 2011; Agarwal, 2012; Beauchesne and Agarwal, 2014). This dissertation also lays the groundwork for a future study to combine these multiple data sets on bone maintenance from both the biomechanically influenced long bones of the upper and lower limbs, along with the hand metacarpals, in order to better understand the synergistic effects of diet and activity on skeletal health.

Chapter Summaries

Chapter 2 provides important background information about the Muisca culture and the archaeological site of Tibanica. A review of some of the central research on Muisca history is presented in conjunction with some of the traditional models that have been proposed for studying chiefdom societies. Results from the emerging research on the Tibanica archaeological site are also discussed to provide a framework for later discussions of this population.

In chapter 3, I present the background, methods, results and discussion of the human diet data for the Tibanica population. The chapter focuses on the stable isotope analysis of 199 individuals and presents these data in relation to status, sex, and age-related patterns.

Chapter 4 examines the physical activity patterns for the Tibanica peoples as evidenced through cross-sectional geometry analysis of 63 individuals' femurs and paired humerii from 33 individuals. Necessary background information about the method, results from previous studies, methods and materials, and results and discussion of the Tibanica data are all presented.

The results from metacarpal radiogrammetry analysis of 75 individuals in order to assess patterns of bone maintenance and loss are presented in chapter 5. This chapter provides a review of the method and applications in archaeological populations, then turns to the results and analysis of the Tibanica sample.

Finally, chapter 6 concludes the dissertation with a review of the overall findings for diet, activity, and skeletal health within this Muisca society. The chapter includes a discussion of how these data sets relate to each other and the implications of this work on understanding living in a Muisca society in light of this new data. Finally, the chapter discusses future work on Muisca archaeology, with a particular emphasis on bioarchaeological contributions to understanding embodied social experience.

Chapter 2: The Muisca

The Muisca cultural group lived in the eastern cordillera of the northern Andes mountain range, located within present-day Colombia. They had large, established settlements in the valleys and high altitude 'savannah' around what is now Bogotá and neighboring towns (such as Tunja to the north, Figure 2.1). The Muisca occupied this northern Andean area for at least 800 years, with the Early Muisca period marked from 800-1200 AD and the Late Muisca period marked from 1200-1600 AD (Langebaek Rueda, 1995). This highland region, known as the Sabana de Bogotá, has evidence of human occupation going back thousands of years, with the emergence of the Herrera cultural period estimated around 800 BC (Delgado, In press; Langebaek Rueda, 1995; Noguera-Santamaría et al., 2015). Cultural and linguistic evidence has suggested the Muisca spoke a Chibchan language at the time of contact, and recent aDNA analyses using haplogroup classifications suggest the ancient Muisca were related to Chibchan groups who are thought to have migrated from Central America into northern South America thousands of years ago (Jara et al., 2010; Noguera-Santamaría et al., 2015). The Muisca are therefore one social group forming a larger Chibchan cultural landscape which extended from southern Central America into northern South America. This region was named the "Intermediate Area" in Gordon Willey's landmark *Introduction to American Archaeology* (1971). This designation indicated that these societies did not belong to the northern Maya cultural groups, nor to the southern Andean cultures (i.e. Inca). Many contemporary scholars are distancing themselves from this pejorative classification and recent archaeological research in Central America and Northern South America aims to redefine these cultural groups on their own terms (Sheets, 1992; Drennan, 1996; Hoopes and Fonseca Z., 2003; Joyce, 2013).

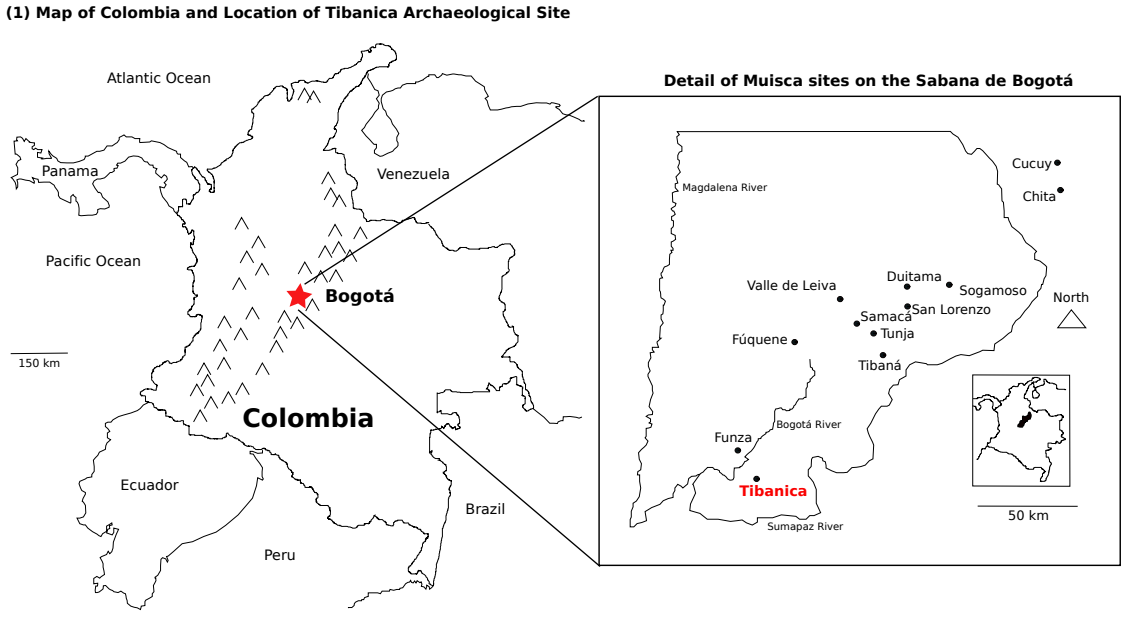

Figure 2.1: Map of Northern South America with detailed inset of important Muisca archaeological sites located within the Sabana de Bogotá, Colombia.

Muisca history has been studied from historical documents and archaeological excavation. The Spanish arrived in the Muisca territory in late 1536 – early 1537 (Haury, 1953; von Hagen, 1974). The documents recorded during the 16th and 17th centuries have played a very significant role in the interpretation and presentation of Muisca sociopolitical life, with much of the documentary evidence used as the primary sources of information, overshadowing archaeological interpretations until relatively recently (Langebaek Rueda, 1995). Historically the Muisca have been presented as an idealized example of a prehistoric chiefdom society, with early historical documents describing the Muisca as a strongly hierarchical society with people occupying various ranks of social power culminating with a Muisca chief controlling his regional territory (Hoopes, 2005; Herrera, 2008; Langebaek, 2008). However, the development of this complex social system through time is still not well understood and many scholars are interested in the emergence of the social relationships that the Spanish documented when they arrived. A majority of Muisca scholarship has focused on identifying power and inequality as it relates to social status, seeking evidence to support the interpretation that the Muisca fit within traditional models of chiefdom societies (Langebaek Rueda, 1995; Langebaek, 2014). Recently scholars are questioning the power and influence that chiefs had over their community (Langebaek Rueda, 1995; Kruschek, 2003; Henderson, 2014; Langebaek, 2014; Argüello Garcia, 2015).

Chiefdom societies are characterized by emergent social inequality not yet institutionalized in a class system (Fried, 1967; Flannery, 1972; Drennan and Uribe, 1987; Earle, 1991; Drennan, 1995; Earle, 1997; Carneiro, 1998). Chiefdoms are often associated with particular kin structures and a redistributive economy but these are not present in all chiefdoms (Drennan, 2008). Given the hierarchical nature of the social organization of these types of societies they present ideal opportunities to investigate the variety of ways that social inequality emerged and was transformed. Archaeologists have studied inequality across many complex societies, for example work in the Americas has debated the emergence and evidence of inequality across numerous cultures (Hudson et al., 1985; Ames, 1994; Clark and Blake, 1994; Pauketat, 1994; Cobb, 2003; Hegmon, 2005). In areas of the Pacific Islands and Africa studies have successfully combined archaeological and ethnohistorical evidence to reconstruct the complex social and political changes of these communities (Earle, 1978; McIntosh, 1999; Schoenbrun, 1999; Kirch, 2005, 2010; De Barros, 2012). The societies of Central and northern South America present important case studies of the emergence of social inequality that persist through time, but ultimately these societies follow alternative trajectories that do not equate to state formation (Langebaek Rueda, 1995; Quattrin, 2001; Hoopes, 2005; Boada Rivas, 2007; Cuéllar, 2009). However, archaeological evidence of strong social hierarchies within Muisca communities has been elusive and the lack of overt evidence calls into question the assumptions of sharply delineated group inequalities (Boada, 1987; Langebaek, 1990; Kruschek, 2003; Hoopes, 2005; Boada Rivas, 2006, 2007; Langebaek, 2008; Henderson, 2014; Langebaek, 2014). The archaeological site of Tibanica (discussed below) presents a unique opportunity to examine possible roots of inequality in earlier Muisca times and the ways that social differences may have supported emergent hierarchies. This dissertation will add to our understanding of inequality in socially stratified societies, by examining how both individuals and sub-groups were affected by and participants in ancient power structures.

There have been a number of theories proposed to explain the emergence of complex societies. The corporate-network continuum theory proposes a variety of paths where different power structures produce various social organizations, including trajectories for high equality and high inequality (also known as the group-oriented versus individualizing modes, or the dual-processualist theory; see: (Renfrew, 1974; Blanton et al., 1996; Blanton, 1998; Feinman, 2010). Central to this theory are the political relationships and circumstances that allow particular types of inequality to develop and become institutionalized, or the social conditions that maintain certain forms of equality. In the extreme 'network' mode, a small number of individuals or a particular group (a 'network') aims to consolidate and maintain power, often controlling particular resources or amassing wealth ('aggrandizers'); in this mode most members of society are excluded from access to these resources (be they economic, political, or ideological). The other extreme is the 'corporate' strategy where power may be shared across particular groups and wealth may be more equally distributed within the society (Blanton et al., 1996; Feinman, 2010). I propose that food consumption behaviors and physical activity patterns reflected in the human body are additional lines of evidence that can be operationalized to understand the range of strategies that particular people or groups may have harnessed in the past to exert power and control and maintain particular forms of social organization.

Heterarchy has been employed as another analytical lens to observe the complexities and subtleties of elements that may operate to produce structural hierarchy (ordered ranking) and/or inequality (Crumley, 1987; Crumley and Marquardt, 1987; Crumley, 1995). Heterarchy aims to explain how inequality and equality can be operating along vertical or horizontal axes (potentially simultaneously) within any society (Crumley, 1987) McGuire notes, "the concept [of heterarchy] leads archaeologists to consider a greater diversity of social categories and multiple ways for these categories to interact" (McGuire, 2011:62). Using this framework, I can study how the biosocial categories of status, age, and sex may articulate in multiple ways and produce nuanced manifestations of inequality simultaneously depending on their points of intersection. Drennan et al. (2010) also encourage us to move towards multiple scales and forms of inequality rather than the typical dichotomies and typologies that have been proposed (see Gnecco and Langebaek, 2014). Human diet and physical labor have the potential for a large range of variation and individuals will fall within the range of extreme possibilities. This dissertation aims to pursue the meanings and nuances of such diverse activities. It is within this larger anthropological discourse that this dissertation project aims to study how other forms of social identity, such as one's age and sex, may have played a significant role in Muisca socio-political life, serving as axes of social differentiation that structured daily life.

Previous Research on the Muisca

The Muisca region was of particular interest to the Spanish and other European nations for the storied wealth it was thought to hold. The myth of "El Dorado," meaning the golden/gilded one, spurred numerous European expeditions to the regions of Colombia, Venezuela, and Brazil primarily in search of gold but also silver, emeralds, salt, and other highly valued resources (von Hagen, 1974). Documents recorded from these periods by explorers/conquistadores, religious missionaries, and other colonists

have provided large amounts of information about Muisca life during these centuries. However, until recently this evidence was relatively unquestioned and viewed as an accurate description of Muisca life, therefore coloring all subsequent studies of Muisca culture (Langebaek, 2014). These records have truly been a double-edged sword for the Muisca – these texts provide rich details of life that cannot be ascertained through archaeology alone, but we must interrogate the motivations and cultural biases of the authors before we accept the writings as accurate or truthful. It is only through further analysis of both archaeological evidence and historical texts that we will gain a greater, more nuanced understanding of the Muisca and their history. With this in mind I will review some of the central research that has been done on the Muisca, noting that these findings may change in future years as further research refines our interpretations.

In 1536-37 the Spanish arrived in the Muisca territory and noted that the Muisca region was divided into four separate polities (Bogotá, Tunja, Duitama, and Sogamoso), with the Bogotá chiefdom, known as the "Zipa" chiefdom, considered the most powerful, and the "Zaque" chiefdom centered around modern-day Tunja considered the second-most powerful (Eidt, 1959; Broadbent, 1966; Langebaek Rueda, 1987). It is thought that at times the chiefdoms united and at times they were in conflict, both with each other and with neighboring societies (Eidt, 1959). Documentary records suggest that a male chief ruled each chiefdom (though the Muisca are considered matrilineal as documents indicate status was inherited through female lineages), and below that chief there were clear ranks of power distributed over community members (Villamarin and Villamarin, 1975; Helms, 1980). These social rankings have been assumed to correlate to socio-political and economic power, with many scholars focusing on how to identify elites in the archaeological record though settlement, artifact, and burial patterns (Langebaek Rueda, 1995; Boada Rivas, 2007; Drennan et al., 2010).

Two main hypotheses have been proposed for understanding Muisca prehistory, and both center on social relationships and inequalities. The first proposes that social hierarchy developed early in the Muisca cultural history and was marked by a small group of elites controlling land and labor, while the second suggests that the levels of social hierarchy observed by the Spanish were a relatively recent phenomenon and that there was less control of land and labor by elites (Langebaek, 2014). Archaeological data from Muisca sites vary through time and space and at times are contradictory. However, the most recent reviews of archaeological data and historical documents lend greater support to the second hypothesis, suggesting that chiefly power was quite limited, especially related to local economies, and that extraction of labor and materials from others may have not have been as important as previously suggested (Langebaek Rueda, 1987; Kruschek, 2003; Henderson and Ostler, 2005; Langebaek, 2014).

Archaeological evidence show that Muisca settlements changed through time, becoming increasingly concentrated nucleated villages with higher population densities and differing amounts of goods between those of elite or non-elite status (Langebaek Rueda, 1987, 1995; Kurella, 1998; Kruschek, 2003; Henderson and Ostler, 2005; Boada Rivas, 2007). Potential warfare between groups for territory and/or resources has been suggested (Langebaek Rueda, 1995; Boada Rivas, 2007). Well-developed agricultural systems likely provided a strong base for the Muisca economy (Broadbent, 1968; Langebaek Rueda, 1987; Kurella, 1998; Boada Rivas, 2006). Mounting evidence suggests that elites did not control agricultural production or craft specialization, though

elites in some communities may have had access to better agricultural land (Langebaek Rueda, 1995; Kruschek, 2003; Boada Rivas, 2007). Recent work has questioned the often posed top-down elite control/redistribution models for Muisca communities, such as the work of Kruschek (2003) who did not find evidence of elite control over agricultural production despite the oft-cited historical documentation of powerful, controlling Muisca chiefs. A survey of agricultural fields in the area of Valle de Tena by Argüello Garcia (2015) did not indicate a role for vertical economies (as have been suggested for other Andean communities see Murra, 1981; Van Buren, 1996), instead, supporting community use of fields which would have supported the local economy, therefore rebuffing the chiefdom models that focus on elite control and redistributive economies (Argüello Garcia, 2015). Scholars such as Langebaek (1995, 2014) argue that inequality within the Muisca chiefdoms may not have been manifest through agricultural resource monopolization, a hypothesis that can be tested by analyzing both the diets and activities of Muisca peoples.

Information about Muisca food practices can be recovered from multiple sources including historical documents, paleoethnobotanical and zooarchaeological materials, ceramic and lithic analyses, and stable isotope studies. Some of the documents recorded by the Spanish and other early colonists of Muisca territory mention plants, animals, and related food activities. Illera (2012) compiled references about traditional foodways from Colombia culled from historical texts, including notes from a 1620 document from Tunja (located in the northern Zaque Muisca chiefdom). The foods noted include many types of fish (and the use of canoes for navigating local waterways), waterfowl, deer, rabbits, maize, tubers, beans, fruit trees (including plantains, guayabas, and avocado though some of these may have been brought into the area during the early colonial period as cows and wheat are also mentioned, which are Old World foods), honey, and also indicated are the location of salt sources (Illera, 2012). Importantly, it was noted that "la comida más ordinaria de los indios de esta tierra, es maíz y turmas, algunas verduras con un poco de sal y ají; la bebida es la que llaman chicha, que se hace de maíz" (Illera, 2012:76), which states that typical meals of the indigenous peoples (Muisca) were maize, tubers, greens/vegetables with salt and chile pepper, and chicha, a fermented drink made from corn. Chicha was likely an important beverage for the Muisca as it was mentioned in many historical texts, and ceramic vessels thought to have been used for fermenting the drink have been recovered from numerous Muisca sites, with many scholars associating this drink with feasting and other ritual activities (see Chapter 3, this dissertation; Langebaek, 2005).

Archaeological evidence has shown that many Andean crops such as tubers (*Solanum*), maize (*Zea mays*), squash (*Cucurbita*), quinoa (*Chenopodium* spp.), achira (rhizomes of *Canna*), and fruits from neighboring regions were important (Eidt, 1959; Cárdenas-Arroyo, 2002). Protein sources included guinea pig (called curí, *Cavia porcelus*), ducks and other birds, deer, dog, and fish (de Alba, 1945; Cárdenas-Arroyo, 2002). Ethnohistorical documents of Muisca food practices at the time of the Spanish conquest indicate that particular foods such as deer meat and exotic fruits were restricted for only individuals of high status (Castellanos, 1955). A few studies have used stable isotope analysis to investigate Muisca diets using small samples from a couple of sites (Cárdenas-Arroyo, 2002; Langebaek et al., 2012c). These studies found a surprising amount of C_4 plant contribution (maize) to the carbon isotope values of the Muisca

samples and higher rates of meat consumption than expected (Cárdenas-Arroyo, 1993, 1996). This dissertation will provide new dietary data from isotopic analyses of human skeletal remains, focusing on dietary patterns over the lifetime and how food practices may reveal social identities and inequalities as they intersect with sex and age.

Food procurement and production activities (agriculture, hunting, gathering, fishing) are one of the most fundamental aspects of daily life. Food and labor are deeply intertwined, as people spend significant time and effort working to create or find food, and divisions of labor along the lines of status, sex, and age may have structured activity patterns for the Muisca. Rojas de Perdomo (1994) citing Vicente Basilio Oviedo stating, "La adecuación de los terrenos, cuido del cultivo, coshecha y comercio eran tarea masculine; en cambio la labor de siembra la realizaban las mujeres, por considerar que ellas pasaban su fertilidad a los terrenos. Su principal herramienta era la coa o palo plantador, igual que en las otras áreas americanas. Usaron la ceniza resultante de la quema de los terrenos a manera de abono" (Rojas de Perdomo, 1994:195). This quote tells us that work in the agricultural fields, care for crops, harvest, and trade were all areas of male work. The work of sowing seeds was done by the women, with the belief that women pass their fertility to the fields. Oviedo noted that the principal tool used was a pointed stick/digging stick, similar to those used in other areas of the Americas, and that they burned fields and used the resulting ash as a fertilizer. This reference suggests that there may have been a gendered division of labor within Muisca society, with particular kinds of activities associated with male work while other tasks would have been women's area of specialization. Chapter 4 of this dissertation examines evidence of physical activity patterns for a Muisca community, particularly noting sex- and age-related divisions of labor.

Other important aspects of the Muisca economy involved craft specialization, with the production of fine cotton textiles, advanced metalworking, ceramic production and salt production as central to the Muisca traditions (Burland, 1951; O'Neil, 1974; Langebaek Rueda, 1987; Boada Rivas, 2007; Cardale Schrimpff, 2015). Cardale Schrimpff (2015) examines archaeological, historical, and ethnographic evidence of the history of salt production in the Sabana de Bogotá, noting that the refinement of salty brine and trade of this product throughout and beyond Muisca territories was likely an important aspect of the prehistoric economy. Cardale Schrimpff also mentions that a Spanish document noted that women played a key role in the production of salt, attending to evaporating the brine over many hours within their homes, while men were responsible for procuring the firewood needed to maintain the required fire (Cardale Schrimpff, 2015). The information recorded in historical documents provides a unique line of evidence of Muisca culture, potentially revealing aspects of Muisca lifestyles that are difficult to access through archaeological analysis alone. However, it is only through comparing and contrasting both archaeological evidence and historical texts that we will work towards presenting the most complete picture of Muisca history.

Archaeological Studies of Tibanica

The site of Tibanica, located in present-day Soacha, Colombia, is an ideal location to study emergent and continuing inequality in the context of a complex society. During the construction of modern housing in Soacha, a large archaeological site with evidence of materials associated with the Muisca cultural group was uncovered and subsequently

excavated. Approximately 2.8 hectares of the site were excavated in 2007 and 2008 and revealed the existence of archaeological materials including evidence of settlements (via postholes), faunal and botanical remains, pottery and lithics, and skeletal remains of more than 600 people (Bernal A. and Langebaek, 2012). Four distinct burial groups were identified at the site, giving the appearance of a ring-shape, a settlement pattern that has been noted at other Muisca sites (Figure 2.2; Bernal A. and Langebaek, 2012). Burials were rectangular in construction, with most individuals facing south or east. A small number of circular structures were noted by the presence of postholes, and these structures were also noted to follow the same ring-shaped distribution across the site (Figure 2.3; Bernal A. and Langebaek, 2012).

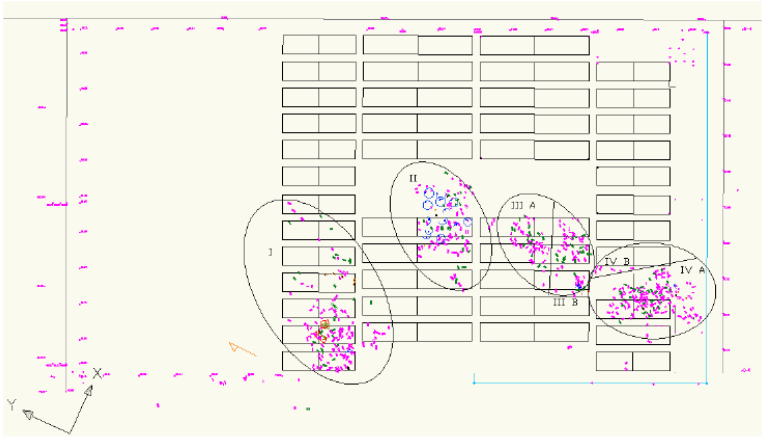

Figure 2.2: Spatial distribution of burials from the archaeological excavation of Tibanica. Note that four burial clusters were identified and labeled I, II, III, and IV, with a small number of individuals buried outside of these distinct groupings (subsequently labeled burial group 0 in data reported within this dissertation). Figure originally published in Bernal & Langebaek (2012:37).

Figure 2.3: Excavation photographs showing post-holes arranged in circles indicating presence of structures. Note that the location of burials within and around these structures. Photos originally published in Bernal & Langebaek (2012:44).

Initial work on Tibanica's pottery chronology and three carbon dates placed the site's occupation during the Late Muisca time period, from about AD 950 to 1350 (Langebaek et al., 2011). One of the major concerns for this dissertation research was identifying the site's period of occupation and clarifying if the burial groups were used synchronically or diachronically. I analyzed 16 human skeletal samples for AMS radiocarbon dates at the UC Irvine Keck lab. The ^{14}C dates provided by these 16 human bone samples place the site occupation between 640 and 990 years before present (+/- 20 years; Table 2.1, below). Following standard practice, radiocarbon dates were then calibrated using OxCal online software (version 4.2.4 with IntCal13 atmospheric curve) to provide refined estimates of site occupation, and suggest 400 years of continuous use from about AD 1000-1400 (Figure 2.4). The analysis included individuals from all burial groups and indicate that the burial groups were simultaneously in use during those centuries, allowing for comparisons of individuals within and between burial groups. Therefore, there is evidence of synchronic use of these four burial clusters, not diachronic use (see Figure 2.5). The general Muisca phases have placed the transition from Early to Late Muisca periods around AD 1200, therefore the site of Tibanica was occupied for the last 200 years of the Early period and the first 200 years of the Late period, spanning this transitional time (Langebaek Rueda, 1995). Importantly, these ^{14}C dates confirm that the site of Tibanica was abandoned prior to the Spanish arrival in the 16th century.

Table 2.1: Sixteen skeletal (bone) samples from the Tibanica burial population were analyzed for ^{14}C dates by the UC Irvine Keck AMS Laboratory.

Tibanica Skeletal Sample ID	Burial Group Number	^{14}C age (BP)	±
1054	1	730	20
1027	1	780	15
1050	1	950	15
1021	1	975	20
1157	2	825	20
1166	2	850	20
1191	2	860	20
168	2	910	20
3102	3	640	20
2208	3	900	20
2208_Replicate	3	910	15
3135	3	990	20
3184	4	790	20
3250	4	790	20
3215	4	870	20
2808	No Group	640	20
3151	No Group	640	20

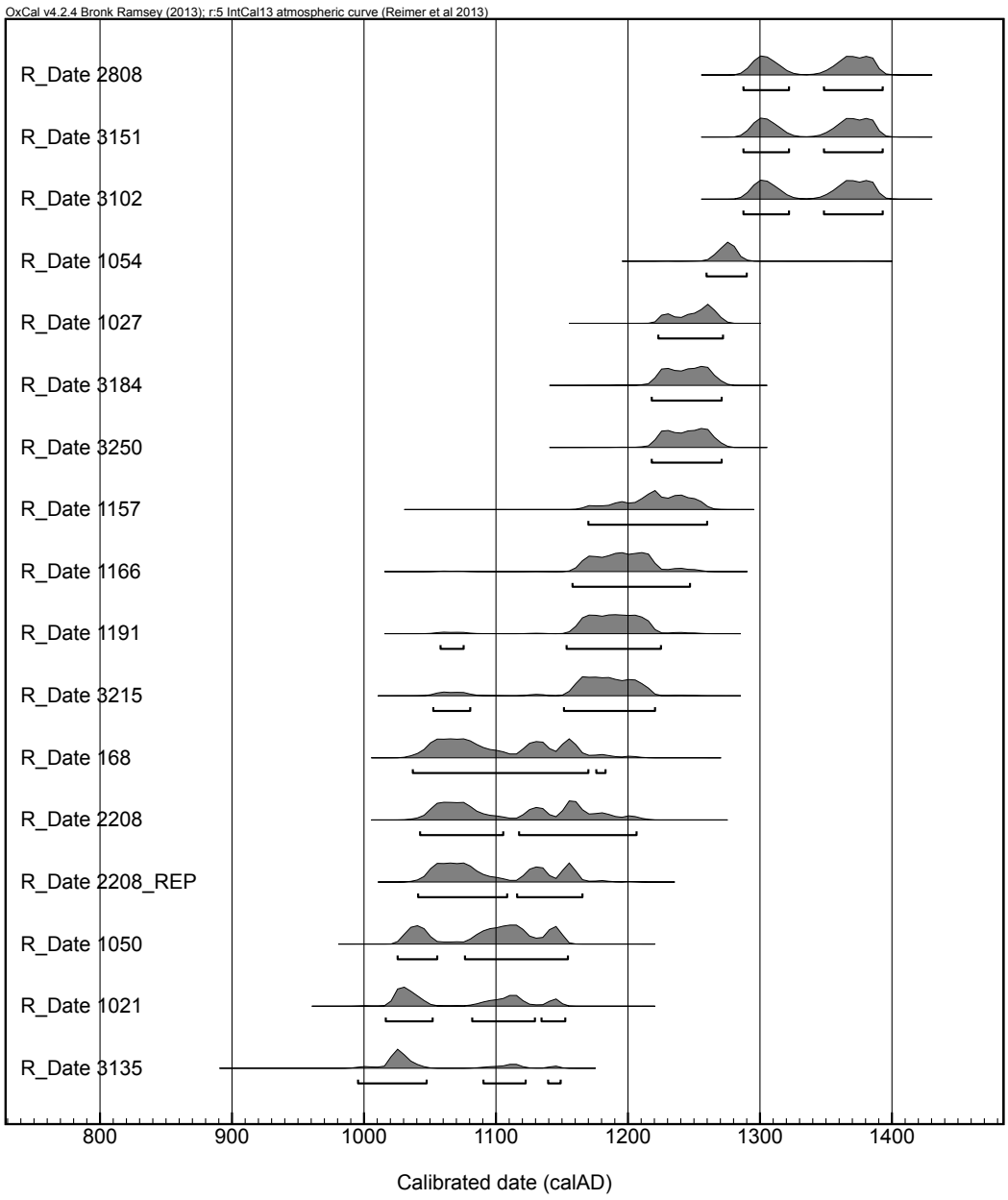

Figure2.4: Calibrated ^{14}C dates from 16 Tibanica skeletal samples indicating the site was continuously occupied from approximately AD 1000-1400. Note that sample 2208 is listed twice to show overlap of duplicate samples. All samples analyzed for ^{14}C dates at the UC Irvine Keck AMS laboratory.

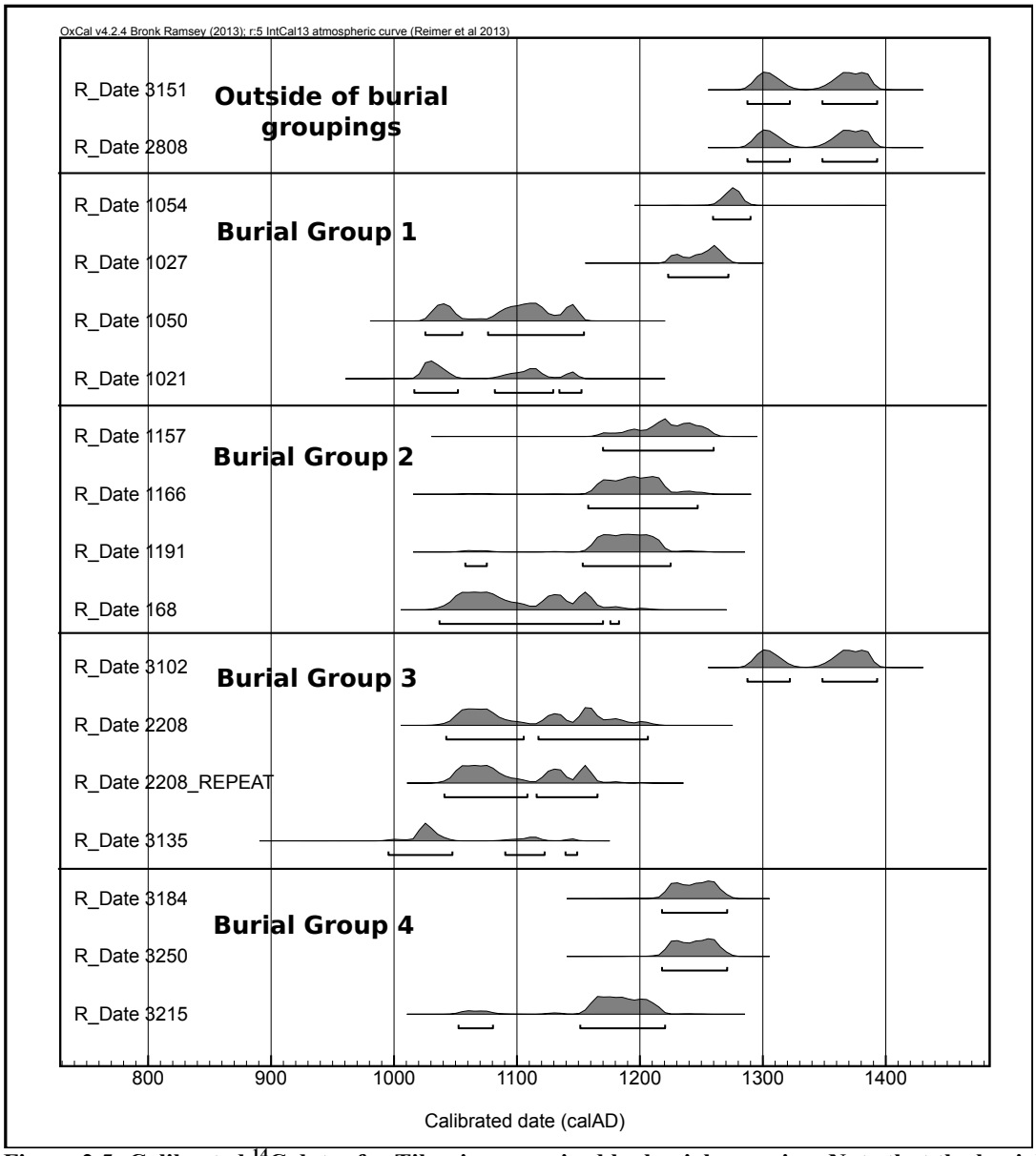

Figure 2.5: Calibrated ^{14}C dates for Tibanica organized by burial grouping. Note that the burial groups show occupations across multiple centuries, indicating that they were in use simultaneously (synchronic occupation). This allows for a comparison of data across and between members of each burial group as any issues of change through time are likely to be distributed within each burial group.

Initial studies of the Tibanica site have focused on understanding the demography and health of the community that lived here. The archaeological materials recovered from the excavation were transferred to the Universidad de los Andes (Bogotá, Colombia) to be studied by project directors Carl Langebaek and Sonia Archila. Subsequent studies have been conducted by a few PhD and MA students, particularly focusing on the large human skeletal sample. Other materials recovered from the site including paleoethnobotanical, zooarchaeological, ceramic, and lithic artifacts are currently being

analyzed by other researchers. Therefore, the interpretations of the data presented within this dissertation may be revised in the future as further information comes to light.

The excavated population includes remains of men, women, and individuals whose skeletal sex could not be determined. All age groups are represented, from infants to old-age adults, with about half of the burial population represented by juveniles. There is also evidence of status differentiation by the presence or absence of durable grave goods (Figure 2.6). High social status has been inferred in this population by the presence of grave goods in association with each individual, with at least 114 burials across all four burial groups containing durable goods. Those burials with burial offerings represent roughly 20% of the excavated burials (Langebaek et al., 2011; Bernal A. and Langebaek, 2012). The most common grave goods were ceramic pots, followed by shell beads. Rarer kinds of artifacts included animal bones (deer and other species), stone and bone tools, and metal artifacts (Langebaek et al., 2012b).

Figure 2.6: Examples of durable grave goods (ceramic pottery and golden objects) found with Tibanica burials. The presence of grave goods in the burial context has been interpreted as evidence of high social status for the Tibanica community. Photos originally published in Langebaek et al., 2012.

Langebaek et al., (2012) performed initial genetic testing of a small sample from Tibanica and found a high amount of diversity with haplogroups A, B, and D represented, with haplogroup A in the highest frequency (Langebaek et al., 2012d). One hypothesis the authors proposed was that individuals buried with grave goods (and therefore considered to be higher status individuals) would have greater genetic affinity to each other, potentially related to inheritance of status through familial lines (Langebaek et al., 2012d). The genetic testing did not support that hypothesis: out of the 24 individuals of 'higher status' tested, only 3 of those individuals appear to be genetically related, suggesting that social status may not be significantly tied to matrilineal inheritance (Langebaek et al., 2012d). An additional study of 30 more individuals of both 'high' and 'commoner' status indicated that 7 of them may have been related (through the matrilineal line), but that almost all of those genetically related individuals came from burials *without* grave goods (Langebaek et al., 2012d). Therefore, assumed higher status

(as indicated by burial offerings) does not appear to be as strongly heritable as once assumed, instead status may have been acquired or achieved through means other than genetic ties.

Disease, nutritional stress, trauma, and other life experiences leave traces on the human body. Skeletal pathologies can occasionally be linked to specific diseases but most pathological conditions can arise from multiple etiologies. A study of 228 individuals from Tibanica (114 with grave goods, 114 without, spanning both sexes and all ages) looked for evidence of cribra orbitalia (CO), porotic hyperostosis (PH), linear enamel hypoplasia (LEH), dental caries, and periostitis (see Table 2.2; Langebaek et al., 2012a). Cribra orbitalia (CO) and porotic hyperostosis (PH) are bony lesions that appear in the eye orbits and on the skull vault in response to numerous conditions including iron-deficiency anemia related to nutritional stress and/or high pathogen loads, though the authors of the Tibanica study only emphasized possible nutritional explanations in their discussion (Walker et al., 2009; Langebaek et al., 2012a). Langebaek et al. (2012) report CO prevalence near 14% and PH at 15% for the sample. Comparisons between individuals with and without grave goods demonstrated significant differences for both CO and PH, showing higher levels of both pathologies in the individuals without grave goods (see Table 2.3). The researchers suggested that the greater frequency of CO and PH in lower status individuals may have been linked to nutritional stress and lower quality diets (Langebaek et al., 2012a). Periostitis is a generalized skeletal response stemming from inflammation of the periosteal connective tissue covering bone and this condition has been attributed to many causes, primarily infection and trauma, though Langebaek et al. (2012) also suggest periostitis could relate to nutritional deficiencies. Periostitis was found in 14% of the sample, and no significant differences were found between status groups for periostitis.

Table 2.2: Presence of skeletal pathologies in a sample of 228 individuals from the Tibanica archaeological collection. Data is derived from Langebaek et al., 2012.

Pathological Condition	Percent with Condition (sample size = 228)
Cribra Orbitalia (CO)	13.6%
Porotic Hyperostosis (PH)	15%
Linear Enamel Hypoplasia (LEH)	14%
Dental Caries	46.9%
Periostitis	14%

Linear enamel hypoplasias (LEH) appear as gaps where dental enamel does not form properly during tooth development, and LEH is associated with severe stress during

childhood. Langebaek et al. (2012a) observed that 14% of the sample had LEH, which they interpreted as a response to nutritional stressors during childhood (though other factors such as parasite load, infection, and overall health status may also cause LEH, see (Goodman and Rose, 1990; King et al., 2005). LEH levels were similar between the groups with and without grave offerings, suggesting that higher status did not confer a better health status overall (particularly during childhood). The most common pathology observed was the presence of dental caries (cavities) in almost half of the sample (47%; Langebaek et al., 2012a). Interestingly, statistically significantly higher rates of dental caries were found in the group of individuals buried with grave goods (in comparison to those without). Dental caries are often associated with diets high in carbohydrates, and the researchers suggested that higher status individuals may have consumed diets with greater proportions of carbohydrate-rich foods. They noted that high rates of maize consumption are correlated to dental caries but they also explained that maize-based diets are often nutrient poor, and the higher status individuals actually showed lower rates of CO and PH (conditions that have often been attributed to nutritional deficiencies though this may not always be the underlying etiology, see Walker et al., 2009). When pathological evidence appears contradictory, we need to consider that multiple etiologies (i.e. disease states) should be considered, and in this case, nutritional status is one possibility amongst many.

Table 2.3: Differences in skeletal pathologies between individuals buried with grave goods and those without. Addition sign (+) means that group had higher frequencies of the pathology, subtraction sign (-) indicates that group had lower frequencies of the pathology, and equal sign means similar frequencies (table adapted from Langebaek et al., 2012).

Pathological Condition	No Grave Goods	With Grave Goods
Cribra Orbitalia (CO)	+	-
Porotic Hyperostosis (PH)	+	-
Linear Enamel Hypoplasia (LEH)	=	=
Dental Caries	-	+
Periostitis	=	=

Ultimately, Langebaek et al. (2012a) suggest that during life the higher status individuals consumed diets that made these people less susceptible to anemic conditions, despite consuming a greater proportion of carbohydrates. Individuals with more than two classes of grave offerings (such as having both animal bones and shell beads) did have lower rates of periostitis and LEH than the rest of the Tibanica sample, suggesting that this very small group of individuals possibly had very well-rounded diets, fewer pathogens, and less metabolic stress. When the authors looked at sex differences within the status groups they found very few differences between men and women. For higher status individuals, men showed a higher prevalence of LEH, while for lower status individuals the females had higher frequencies of dental caries, leading the investigators to conclude that overall, men and women likely had similar levels of nutrition regardless of status (Langebaek et al., 2012a).

Langebaek and co-authors' (2012) study of health indicators for the Tibanica population provides an important line of evidence that suggests that, in general, rates of metabolic stress were relatively low (around 14% for most indicators). The high rate of dental caries (almost half the sample under study) indicate that most peoples' diets were rich in carbohydrates (likely from maize, see Chapter 3, this dissertation). Further research examining dental caries could also examine how age- and sex-related changes may be observed in conjunction with possible dietary changes over the lifetime (see Chapter 3, this dissertation). This initial examination of pathologies for the Tibanica population focused on nutritionally-based explanations for the observed skeletal conditions, and future work should expand on this to consider other possible causes of these same disease states. This dissertation will provide other lines of evidence (dietary practices, activity patterns, bone health through maintenance and loss) that can be combined with the skeletal pathology data to provide a deeper and more nuanced understanding of the relationships between lifestyle and health for members of the Tibanica community. Additionally, future work should examine other kinds of pathological indicators to see if any specific diseases can be observed for this population (such as syphilis, or tuberculosis). Studies of degenerative joint disease would also contribute significantly to our understanding of activity-related stress as it may differentially affect those of high/low status, men/women, older/younger individuals.

An initial study of human diet used stable isotope analysis to examine 60 individuals from the Tibanica population (Langebaek et al., 2012c; Delgado B. et al., 2014). This study indicated that in many cases, bone preservation was good, and therefore the chemical information recorded in the skeletal tissues could be used to reconstruct dietary histories for the Tibanica peoples (Delgado B. et al., 2014). The analysis included individuals of all ages (infants, sub-adults, and adults), both sexes, and high/low status burials in their analysis of bone collagen and bone apatite for carbon, nitrogen, and oxygen isotopes (Langebaek et al., 2012c). This study suggested a mixed diet of C_3 and C_4 plants (see Chapter 3 of this dissertation for more information on stable isotope analysis) with some dietary differences that may correspond to age, sex, and status (some comparisons had small sample sizes and therefore limit interpretations; see Langebaek et al., 2012c). Importantly, the dietary information refutes earlier studies that suggested that Muisca people may have suffered from malnutrition and poor diets (Langebaek et al., 2012c). This research found that dietary differences did not appear to be significant between status groups, a surprising finding given the emphasis in historical texts on dietary privileges for higher status peoples (Delgado B. et al., 2014). One issue with this study was their assignment of sex to sub-adult individuals (including infants and young children). Many bioarchaeologists believe that our current methodologies do not allow for assignment of sex until adulthood due to significant skeletal changes that occur during adolescence (via hormonal influences on the skeleton).

The conclusions of these initial projects from the Tibanica collections suggest that the presence/absence (and elaboration when present) of burial goods are not strictly related to social classes but rather are a marker of social differentiation. However, social differentiation related to wealth does not appear to then be marked by food consumption based on the preliminary isotopic analyses (no differences between burials with/without goods, though possible age- and sex-related differences may have existed). Health indicators suggest similar levels of nutrition and pathogen loads, with some people buried

with grave goods showing fewer markers of metabolic stress. Finally, there is very little evidence that Muisca power was concentrated into particular families, as the genetic data does not show strong familial ties exclusively between those with grave goods. Given these initial findings from the Tibanica archaeological community, I proposed studying a larger sample of the Tibanica population (n=199) to study dietary, activity, and skeletal health patterns over the lifetime, particularly attending to age- and sex-related differences.

Chapter 3: Diet over the Life-course: Sex- and age-related differences within a Muisca community

Introduction

Food is deeply tied to both biological and cultural processes – we eat out of necessity, but what we eat is situated within environmental, economic, political, ideological, and symbolic relationships (Richards, 1951; Douglas, 1984; Mintz and Bois, 2002; Barthes, 2008; Douglas, 2008; Lévi-Strauss, 2008; Twiss, 2012). In this way food consumption habits are intertwined with our identities as they tie us to people and places (Ohnuki-Tierney, 1993; Counihan and Kaplan, 2005; Hastorf and Weismantel, 2007; Twiss, 2007). Anthropologists have focused on the unique relationship that humans have with the food we put into our bodies and how these foods reveal deeper, complex relationships (for example, see Counihan and Van Esterik, 2008 edited volume). Many have asked, why do some of us eat certain things and not others, what disgusts one but is a delicacy for another, who has access to particular foods and why? Archaeologists frequently utilize food remains (botanical and faunal ecofacts) and materials such as pottery vessels to discuss dietary habits of ancient peoples (Gifford-Gonzalez, 1993; Jones, 1996; Bowen, 1998; Bray, 2003a; Atalay and Hastorf, 2006; Coupland et al., 2010). These data have been incredibly valuable to understanding the myriad ways that people use food across time and space to carve out and reinforce cultural experiences that unite and divide them. Stable isotope analyses of key elements like carbon and nitrogen in skeletal tissues are a powerful tool that provides us with information about ancient eating practices, one that can get us direct evidence of what an individual consumed during life and therefore provides a personalized glimpse into ancient lifeways (Richards et al., 2002; Ambrose et al., 2003; Le Huray and Schutkowski, 2005; Reitsema and Vercellotti, 2012).

Food is particularly unique as it is often commodified in ways that allow us to chart the various relationships that it has within a given cultural context. Food and cuisines are often employed in ways that reinforce and maintain hierarchies related to status, gender, and ethnic identity (Malinowski, 1935; Richards, 1951; Appadurai, 1981; Goody, 1982; Sterckx, 2005). It seems almost universal that within every culture there are particular foods that are viewed as "luxury" foods, or as "common" foods, in the same way that some things are considered "food" while other ingredients are viewed as "inedible/disgusting" (Bourdieu, 1984; Douglas, 1984; Rozin et al., 1997; Hastorf, 2003; Glowacki, 2005; Curet and Pestle, 2010). Each culture has its own framework for marking the landscape into things that can be consumed and things that cannot or should not be consumed. Who gets to eat what is a reflection of one's place within a particular cultural space, in addition to reflecting personal habits such as taste (Appadurai, 1981; Rozin et al., 1997).

Consumption habits create and maintain the social body. Archaeologists have been particularly interested in the complex relationships that social stratification and gender have in relation to food access (Spielmann, 1989; Hastorf, 1991; Moss, 1993; Crown, 2000; Twiss, 2012; Cuéllar, 2013). Food is often employed as a marker of status, power, and wealth, and restricted access to these items maintains and reifies the relationships of these foods as identifiers of social position. For example, in early China

the consumption of meat on a regular basis was limited to the rich and powerful, particularly for meats that were considered 'extravagant' or 'exotic' such as turtledoves, wild geese, sika deer, leopard fetus, and bear paws (Sterckx, 2005). When social status impacts diet, then we may be able to observe dietary privilege in individuals with greater social power and possibly dietary impoverishment in individuals of the lowest social status. Gender is a biosocial identity that may be expressed, created, and maintained through food practices as well. Males and females may eat different diets as part of the social expression of one's gender. For example, stable isotope analyses of Maya peoples have documented the complex interactions of food with a person's sex and status in Maya cultural history (White, 2005). White has demonstrated that gender differences in food practices were most pronounced in high status Maya individuals, while commoners of both sexes were more likely to consume similar diets (White, 2005). Meat consumption is also often associated with status and sex, such as the findings by Ambrose et al. (2003) where high status individuals (both males and females) buried in Mound 72 at Cahokia consumed significantly more protein than low status individuals. Other studies have examined age-related variation in human diet, with most focusing on breast-feeding, weaning diets, and transitions to adulthood diet (Fogel et al., 1989; Katzenberg et al., 1993; Wright and Schwarcz, 1998; Dupras et al., 2001; Prowse et al., 2005; Turner et al., 2007; Burt, 2013). Given the complexities of human relations to what we eat, food has been viewed as "embodied material culture" (Bray, 2003b; Dietler, 2007). This idea lends itself well to isotopic analyses of different tissues in the body because these may record of dietary practices from different periods of life (Sealy et al., 1995; Sofaer, 2006; Lee-Thorp, 2008; Burt and Amin, 2014; Reitsema et al., 2016).

Within the Americas the spread of maize (*Zea mays*) has been a central topic of archaeological study (for example see, Staller et al. (2006) edited volume). This crop was adopted across the American continents over time and was incorporated into local economic, political, and ideological systems in numerous ways(Hastorf and Johannessen, 1993; Staller et al., 2006; Staller and Carrasco, 2010). In many parts of South America maize was consumed both as a food and a fermented beverage called *chicha* in the central Andes and *zapcua* in the Muisca Chibchan language (Rojas de Perdomo, 1994). In many cultures throughout South America maize was a plant that was associated with political and ideological power (Hastorf and Johannessen, 1993). Maize is also isotopically unique due to its C_4 photosynthetic pathway (see below) and because the carbon humans eat closely reflect important or common dietary sources, like maize, isotopic studies of human skeletal tissues have documented the adoption of this plant across American cultures through time and space (Vogel and van der Merwe, 1977; van der Merwe, 1982; Schwarcz et al., 1985; Katzenberg et al., 1995; Ambrose et al., 2003).

The ability to track the incorporation of this specific grain into human diets has allowed archaeologists to go beyond mere identification of maize presence/absence and further explore the social relationships that may be intertwined with maize consumption. Access to maize has been tied to social status and/or sex in some groups within cultures such as the Maya (White et al., 1993; White, 2005; Wright et al., 2010), the Tiwanaku (Berryman, 2010; Somerville et al., 2015), and the Inca (Hastorf, 1991; Hastorf and Johannessen, 1993; Turner et al., 2010). Historical documents that discuss the northern South American pre-Columbian Muisca peoples, mention the importance of maize and potatoes in the local diet, and also emphasize that *chicha* beer made from corn was an

important foodstuff that was regularly consumed (Llano Restrepo and Campuzano Cifuentes, 1994; Rojas de Perdomo, 1994; Langebaek et al., 2012c). This study examines human skeletal tissues for isotopic evidence of the dietary practices of Muisca people. Since food practices can reveal underlying relationships within any community, this project aims to investigate how a persons' status, sex, and age may have played a role in access to resources within a Muisca population. I hypothesize that maize and meat will be foods that are associated with higher status individuals and males (similar to other studies in pre-Columbian Mesoamerica and South America). If maize was linked to Muisca social identities such as one's gender, age, or social status then I may be able to reveal these relationships through isotopic analysis of skeletal tissues.

This study also takes a life-course approach to investigating human dietary histories. The human body is a repository of both biological and social experiences that can be traced through the skeleton (Larsen, 2002; Armelagos, 2003; Sofaer, 2006). Stable isotope research can study childhood dietary practices through analysis of teeth, which do not change during life, in comparison to bone, which is constantly changing and being replaced during life, therefore integrating adulthood diet information (Sealy et al., 1995; Balasse et al., 1999; Fuller et al., 2003; Berger et al., 2010; Reitsema and Vercellotti, 2012). Studying dietary stability or change over an individual's lifetime can provide a more nuanced understanding of how social identities change or remain stable as one ages. For example, some foods may be tied to gender but might not be adopted into diet until puberty or early adulthood, while other foods may be tied to status which may be incorporated during childhood (if status is inherited) or later in life (if status is acquired). Examination of childhood diet in comparison to adulthood diet can potentially reveal dynamic social relationships and identities of Muisca peoples through their food practices. I hypothesize that the childhood diets of high status individuals will reflect privileged access to resources including maize and meat during their youth. I hypothesize that overall, the diets of male and female children will be similar.

Muisca Foodways

The Muisca were an agricultural society, with potatoes and maize likely making up the base of the diet in conjunction with numerous other plants growing well within their territory (Broadbent, 1964, 1968; Langebaek Rueda, 1987; Kurella, 1998; Rodríguez, 2010). The Sabana de Bogotá is a fertile high-mountain plain (2600 masl) with two rainy seasons per year, allowing for up to two harvests in many areas. The gold objects that Muisca people crafted are probably the best known artifacts from their culture. However, gold mines were not known to have existed within their territory, instead the Muisca established strong trade networks with surrounding territories where gold mines did exist (Eidt, 1959; von Hagen, 1974). The Muisca did have large salt and emerald mines within their region, so these items were traded both within local economies and to neighboring groups (Eidt, 1959). The Spanish noted the beautiful, painted textile clothing and blankets that the Muisca wore, traded, gifted, and gave as tribute (Eidt, 1959; von Hagen, 1974). The historical documents indicate that regular trading markets occurred in a couple of established locations within the Muisca territory, and also at particular outposts on the peripheries to trade with outsiders (Eidt, 1959; Illera, 2012). These trade networks allowed for the circulation of goods (food, clothing,

tools and other crafted wares) both within Muisca networks and with neighboring communities.

Previous research on Muisca food ways have indicated a wide range of foods that were likely consumed. Multiple historical and archaeological sources suggest that potatoes and maize formed the food base with numerous other crops also probably important such as yuca (*Manihot*), beans (*Phaseolus* spp.), squash (*Cucurbita* spp.), quinoa (*Chenopodium* spp.), achira (*Canna edulis*), and many types of fruits (see Appendix A). Protein sources also appear to have been varied and included guinea pigs (known as *curí* to the Muisca, *Cavia porcellus*), birds such as ducks (Anatidinae), dogs (*Canis familiaris*), deer (*Odecoileus* spp.), fish and other aquatic animals like crabs (see Table 3.1; (Cárdenas-Arroyo, 1993; Rojas de Perdomo, 1994; Cárdenas-Arroyo, 2002; Illera, 2012). The documentary record is important because it notes two major food classes that were restricted to those of high social status. Exotic fruits were one group of foods that were supposedly limited to only those of high status, probably as these were harder to obtain and therefore may have required more capital to trade with. Deer meat was also mentioned as being an important food that only the chief and those of very high ranking were allowed to consume (Castellanos, 1955). Interestingly, archaeological studies have documented deer bones at many Muisca sites, including the archaeological site of Tibanica where the materials for this study originated. Due to the historical documents framing deer as a privileged resource the presence of deer bones in particular contexts has been interpreted as evidence for higher status when found in settings such as burials or other structures (Boada Rivas, 2007). Coca (*Erythroxilum coca*) leaf use was also important for the Muisca though this was likely not a major contribution to dietary chemistry as coca is not usually swallowed. Stable isotope analysis of skeletal tissues presents a unique opportunity for both individual and communal dietary comparisons. One hypothesis that can potentially be tested is whether those of high status did indeed have special access to foods such as deer or maize.

As discussed in the previous chapter, a few studies have used stable isotope analysis to investigate Muisca diets using small samples from a couple of sites (Cárdenas-Arroyo, 2002; Langebaek et al., 2012c). These studies found a surprising amount of C_4 plant contribution (maize) to the carbon isotope values of the Muisca samples and higher rates of meat consumption than expected (Cárdenas-Arroyo, 1993, 1996). An initial study of a small sample of the Tibanica individuals for bone collagen carbon and nitrogen isotope data showed potential differences between individuals of high and low status (though not statistically significant, possibly due to sample size; (Langebaek et al., 2012c). The success of recovering good quality collagen data and the initial findings of potential dietary differences within the Tibanica community warranted expanding the isotopic work to address the questions proposed here.

Background: Stable Isotope Analysis for Dietary Reconstruction

The foods that an animal consumes provide the chemical building blocks for creating and maintaining body tissues, hence the popular phrase "you are what you eat" (van der Merwe, 1982; Ambrose, 1993; Lee-Thorp, 2008). Chemical analyses of skeletal tissues reveal the long-term dietary averages during particular periods prior to death. The most common stable isotopes used to study human diet are carbon and nitrogen, whose elements exist in multiple forms, called isotopes. An isotope has the same number of

electrons and protons but a varying number of neutrons, causing a mass difference between the isotopes (such as 12-carbon has 6 neutrons versus 13-carbon which has 7 neutrons). An isotope ratio mass spectrometer is capable of measuring the ratios of these isotopes. These are expressed in delta notation, δ, as parts per thousand, known as per mil (‰):

$$\delta = [(R_{sample}/R_{standard}) - 1] \times 1000$$

where $R = {}^{13}C/{}^{12}C$ for the measurement of carbon, for example. Today, the standards the samples are compared to are the limestone Vienna PeeDee Belemnite (VPDB) for carbon and oxygen, and atmospheric N_2 (AIR) for nitrogen. Most plant and animal tissues have less ^{13}C than the PDB standard so the delta values for these are typically negative. Current AIR nitrogen is about 0 delta units, with most plants and animals more enriched in ^{15}N and therefore these have positive nitrogen delta values (Ambrose, 1993; Dawson and Brooks, 2001). Carbon is found in both the organic (collagen) and inorganic (hydroxylapatite) fractions of bone and teeth while nitrogen is found in the organic portion of each tissue or in other tissues like hair or muscle.

Carbon isotope data is used to distinguish terrestrial plant consumption into major categories of plant-based foods from plants that have different ways of fixing their carbon, called C_3 and C_4 plants (reflecting the number of carbon atoms in the first compound produced during photosynthesis). The carbon isotope composition of plants can also allow investigators to parse out terrestrial from marine foods in environments where aquatic sources may have been included (Schoeninger and DeNiro, 1984; Barrett and Richards, 2004; Newsome et al., 2010). Since C_3 and C_4 plants use different photosynthetic pathways, these different physiological mechanisms cause distinct carbon isotope fractionation within those plants. Most plants that humans consume use the C_3 carbon pathway while a few important plants use the C_4 pathway (such as maize, sugar cane, sorghum, millet), and some use an intermediate pathway called CAM (such as some types of cacti/succulents which may be consumed by humans). C_3 and C_4 plants are isotopically very distinct from one another, with modern C_3 plants having an average $\delta^{13}C$ value around -26‰ while C_4 plants have an average $\delta^{13}C$ values around -12‰ (‰, or per mil units are parts per thousand, see below and (Smith and Epstein, 1971; Smith, 1972; O'Leary, 1988). When humans and other animals consume these plants their carbon chemical signature is incorporated into bodily tissues and therefore diets that are dominated by plants from one group or the other (C_3 vs C_4) can be distinguished.

Nitrogen is incorporated into the organic portion of bones and teeth and is related to the protein sources that an animal consumes. Nitrogen can help reveal the primary food items consumed, and therefore where an animal fits within a large food-web because nitrogen isotope values increase between 3 and 4‰ as consumers feed on successively higher levels in the local food chain (Minagawa and Wada, 1984). For example, legumes have $\delta^{15}N$ values around 0‰ (they harbor nitrogen fixing bacteria in their roots that fix atmospheric nitrogen and therefore have $\delta^{15}N$ similar to air), and an animal that consumes those legumes will have a $\delta^{15}N$ of about 3.5‰ (a step-wise increase from producer to consumer). Then an omnivore, who consumes that animal will have a $\delta^{15}N$ of about 7‰, and a carnivore who consumes the omnivore will have a $\delta^{15}N$ of about 10 to 11‰, showing increasing enrichment from the original legume at the base of the food

web (Deniro and Epstein, 1981; Minagawa and Wada, 1984). Terrestrial food webs often only have a few trophic levels (commonly 3 to 4), with primary producers being plant-based, and therefore nitrogen isotope values usually range between 0-12‰ for most animals. However, recent work examining nitrogen isotope data from a range of plants and animals has revealed a more complex relationship in both nitrogen cycling and in how plants with different microbial interactions can vary (Craine et al., 2009), requiring further investigation to understand the limitations of interpretation of terrestrial animals' nitrogen isotope data (Szpak et al., 2013; Szpak, 2014). Marine food webs have many more trophic levels and therefore top-level predators often have $\delta^{15}N$ values as high as 15-20+ ‰ (Schoeninger and DeNiro, 1984; Graham et al., 2010). The Muisca site of Tibanica is located high in the northern Andean mountains and while long-distance trade may have brought marine seafood into the area this most likely would have been a rare foodstuff and not have been a regular supply to influence stable isotope diet data. The site is located near freshwater rivers which may have provided fish, crabs, and other aquatic resources to the Tibanica peoples. Freshwater aquatic systems can mimic both "C_3" and "C_4"-type isotopic signatures in carbon and nitrogen values, making it difficult to tease apart the possible contributions of these foods on isotope data alone (Miller et al., 2010).

Skeletal tissues are a composite material that combine an inorganic crystalline hydroxylapatite structure with an organic collagen matrix, each of which provides different data related to consumed diet. The organic collagen portion provides $\delta^{13}C$ and $\delta^{15}N$ data and is skewed towards the protein sources from the diet (Ambrose and Norr, 1993; Tieszen and Fagre, 1993). Collagen carbon $\delta^{13}C$ is about 5‰ more positive than the dietary carbon (so if you eat C_3 foods averaging -21‰ your bone/dentin collagen $\delta^{13}C$ will be around -16‰ (Van Der Merwe and Vogel, 1978; Sullivan and Krueger, 1981; Lee-Thorp et al., 1989). Bone turnover also plays a role in the interpretation of skeletal dietary records, with cortical bone taking at least 10 years to remodel while other bones may turnover in slightly less time (Hedges et al., 2007; also see references in Ubelaker and Parra, 2011).

The inorganic hydroxylapatite matrix ($Ca_{10}(PO_4)_6(OH)_2$) from bone and enamel apatite also provides $\delta^{13}C$ data. The carbon that forms this matrix is drawn from blood carbonate which pulls carbon from all dietary sources (carbohydrates, proteins, and lipids) and therefore this skeletal carbon data is a better representation of overall diet (Krueger and Sullivan, 1984; Passey et al., 2005). Bone apatite carbon $\delta^{13}C$ and tooth enamel $\delta^{13}C$ is about 10‰ more positive than the diet, so if your bone apatite/enamel carbonate $\delta^{13}C$ is -11‰ then your average diet was -21‰ (Schoeninger and DeNiro, 1982; Krueger and Sullivan, 1984; Schoeninger and DeNiro, 1984; Lee-Thorp et al., 1989; Ambrose and Norr, 1993). By analyzing both the organic and inorganic fractions of skeletal tissues we can get a more holistic understanding of ancient dietary practices.

By analyzing both teeth and bone we can compare diets from childhood to adulthood and look at changes or stability in dietary practices over a persons' lifetime (Sealy et al., 1995). Teeth form at discrete periods of time and are thought to be highly genetically controlled for their development and eruption into the mouth (Hillson, 2005). Since teeth form within a relatively small range of time during childhood and adolescence, we can selectively sample particular teeth to capture dietary data from specific periods of youth. For example, this study preferentially sampled second molars, which form their enamel cap between ages 5-9, and third molars, which form their

enamel cap between ages 9-15 in order to study diet that would reflect childhood periods that were not influenced by breastfeeding and weaning (Moorrees et al., 1963; Ubelaker, 1979; Schaefer et al., 2009). Unlike teeth, bone are not a static skeletal tissue and instead are constantly remodeling during life in response to various needs of the body (Martin, 2003; Ruff, 2005; Robling et al., 2006). Therefore, with bone turnover thought to happen about every 10 years, the tissue's chemistry then reflects the average diet from approximately the decade preceding death (Hedges et al., 2007).

Materials and Methods

Plants: Modern Reference Collection

A modern plant reference collection was harvested and analyzed for $\delta^{13}C$ and $\delta^{15}N$ isotope data in order to assess the range of values that may have contributed to ancient diets and provide a local isotopic data set to compare with the human data. The plants were grown on a farm in Tequendama, about 8km from the archaeological site, without any chemical fertilizers or other inputs to the soil. Indigenous plants were selected with the assistance of a paleoethnobotanist (Jennifer Salinas) in order to reflect foods that may have been consumed by prehistoric Muisca peoples, some of which have been found in archaeobotanical studies, and others noted in historical documents and Chibchan linguistic texts (Rojas de Perdomo, 1994; Cárdenas-Arroyo, 2002). However, the collection was limited to what the modern family living on this farm was growing for their own table/tastes, and therefore does not reflect the full range of plant foods the Muisca people most likely consumed. For example, I could not get a quinoa (*Chenopodium*) or bean (*Phaseolus*) sample during this growing period but those may have been important crops. Plant samples were washed in the field and imported to the USA for analysis. Samples were freeze dried and then analyzed for carbon and nitrogen isotope data at the Center for Stable Isotope Biogeochemistry at UC Berkeley (see below for analytical information). Fifty-four plant samples were analyzed for C and N isotope ratios and represent twenty-four plant species. Many plants were sampled across multiple tissues to document the range of isotope values any one plant part may have (see Appendix A).

Skeletal Samples

199 individuals from the Tibanica archaeological collection were selected for study, covering a range of adults of different ages and both sexes (n = 73 females, n = 98 males, n = 28 unsexed; Appendices 2 and 3). Sex and age at death were determined following standard protocols, focusing on the pelvis (pubic symphysis and auricular surface) and the skull (Lovejoy, 1985; Brooks and Suchey, 1990; Buikstra and Ubelaker, 1994). Human bone samples were opportunistically chosen from long bones that were already broken, and in cases where all long bones were intact a broken rib was sampled. In addition to the human skeletal samples, six faunal samples collected from the archaeological site of Tibanica were also included for study. They were identified to genus level by zooarchaeologist Catolina Zorro at the Universidad de los Andes, Bogotá, Colombia. All bone samples were mechanically cleaned using a handheld Foredom rotary tool at low speed and any adhering trabecular bone was removed so that only cortical bone was sampled. Bone samples were reduced to a fine powder using the rotary tool.

All tooth samples were molded using dental silicone prior to sampling in order to retain an exact replica that could be analyzed if further morphological or tooth-wear analysis is of interest to future projects. Second molars were preferentially selected, followed by third molars. A small number of individuals had no molars present and therefore a premolar, first molar, or incisor was selected (n = 18 individuals) but these teeth may have incorporated dietary information from breast milk and weaning diets, therefore those isotopic results are not discussed here. Five individuals had no teeth in their mandible or maxilla and therefore lack childhood dietary data (most of these are older aged individuals). Teeth were sampled for both enamel and dentin using a handheld Foredom rotary tool with a diamond coated drill bit at low speed. Enamel was bulk sampled starting from the cementum-enamel junction (the last part of the enamel cap to develop) and moving up towards the occlusal surface (most samples covered an area of about 3-4mm from the CEJ towards the occlusal surface, with very few samples having enamel from the upper part of the tooth included both because sample size had already been attained and because tooth wear meant much of the occlusal surface was worn away). Dentin samples were drilled from the same area directly underneath the enamel surface that was removed.

Collagen from bone and tooth dentin was chemically extracted following standardized protocols (Sealy et al., 1995; Waters-Rist and Katzenberg, 2010; Sealy et al., 2014). Powdered bone and tooth dentin was exposed to 0.5N HCl for at least 24 hours, and changed daily until the sample was demineralized. After demineralization samples were rinsed to neutral with ultrapure water and then soaked in 0.1M NaOH overnight (12 hours). Samples were again rinsed to neutral and then freeze dried. Collagen samples were analyzed at the Center for Stable Isotope Biogeochemistry (CSIB) at UC Berkeley on a CHNOS Elemental Analyzer (vario ISOTOPE cube, Elementar, Hanau, Germany) coupled with an IsoPrime 100 mass spectrometer (Isoprime, Ltd, Cheadle, UK). Samples were analyzed with NIST standards (SRM 1547 peach leaves, SRM 1577c bovine liver), IAEA CH6 (sucrose), and internal project bone and tooth standards (MJM1 dentin, MJM1 enamel, MJM2012 bone). Long-term precision of the mass spectrometer is reported at ±0.1‰ for carbon and ±0.15‰ per mil for nitrogen. Carbon isotope data ($\delta^{13}C$) is reported to the VPDB standard, and nitrogen isotope data ($\delta^{15}N$) is reported versus the AIR standard.

Collagen preservation was assessed using a combination of measures including percent yield, %C, %N, and C/N ratio. Well preserved bone collagen has a carbon content around 45% and about 15% nitrogen, therefore corresponding to atomic C/N ratios between 2.9 and 3.6, and samples with values within this range are thought to best retain their biogenic isotopic data (DeNiro, 1985; DeNiro and Weiner, 1988; Ambrose, 1990, 1993). Of the samples analyzed, 168 had good bone collagen and 176 tooth samples had good dentin collagen. Any samples with C/N ratios outside of this range were excluded from subsequent analysis and interpretation. The percent yield of collagen is often used in determining if any samples are potentially too poorly preserved to analyze, with some scholars using between 1-5% yields as the low-end cut-off while others will go below 1% yield (Ambrose, 1990; Schwarcz and Schoeninger, 1991; van Klinken, 1999). Percent yields for the Tibanica samples ranged from 1 to 23%, suggesting good preservation of collagen in most samples.

Apatite carbonate from bone and tooth enamel was chemically extracted following standardized protocols (Koch et al., 1997). Powdered samples were exposed to sodium hypochlorite (bleach, 2.5%) for 24 hours (enamel) or 48 hours (bone, with a refresh of bleach after 24 hours). After the bleach treatment to remove the organic fraction, samples were rinsed to neutral and then 0.1M acetic acid was added to samples (4 hours for bone, 12 hours for enamel). Samples were again rinsed to neutral and freeze dried. Carbonate samples were analyzed at CSIB on a GV IsoPrime mass spectrometer with Dual-Inlet and MultiCarb systems with international standard NBS 19, two lab standards, and internal project standards (MJM1 enamel, MJM2012 bone). Samples are reported relative to the VPDB standard for both $\delta^{13}C$ and $\delta^{18}O$. The lab reports long-term precision measurements at ±0.04‰ for carbon and ±0.07‰ for oxygen.

Tooth enamel apatite is thought to be an incredibly robust tissue due to its highly crystalline structure and is thought to be less likely to be affected by diagenetic processes that would alter the chemical composition of this material (Lee-Thorp, 2008). Bone is thought to be more susceptible to chemical alteration postmortem and therefore the inorganic apatite carbonate maybe affected by diagenetic changes (Lee-Thorp, 2008). A number of researchers are now employing techniques such as FTIR, ATR-FTIR, and Raman spectroscopy to assess aspects of bone structure preservation as a proxy for the chemical integrity of the underlying substrate (Hollund et al., 2013; Beasley et al., 2014; Halcrow et al., 2014; Pestle et al., 2015a). These methods assume that there is a high correlation between structural and chemical integrity – it is thought that if the archaeological bone retains the same structural properties of well-preserved bone then the chemical composition of the bone reflects a biogenic isotopic signature rather than a diagenetic one. This project analyzed bone apatite samples at Cal State Chico and UC Berkeley using ATR-FTIR (Attenuated Total Reflectance-Fourier Transform Infrared Spectroscopy). ATR-FTIR is one method used to study bone structure, utilizing infrared light to provide a spectral graph of a sample, which can then be compared with well-preserved modern samples (see Beasley et al., 2014).

187 bone apatite carbonate samples were analyzed using ATR-FTIR at Cal State Chico (n=160 unique samples) and/or UC Berkeley (n=27 unique samples), a few samples were too small to analyze and 11 samples were analyzed in both labs for inter-lab comparison. Of those samples analyzed, over half (n=111) of the samples have bone measures considered 'good' for both the infrared splitting factor (IR-SF) and carbon to phosphate ratio (C/P) values (Hollund et al., 2013; Beasley et al., 2014; Somerville et al., 2015). An additional 30 samples had 'good' data for either IR-SF or C/P values, but not for both measures. Finally, 58 samples had bone measures (IR-SF and C/P) that were both outside of the ranges considered 'good' for those aspects of bone preservation and those samples were excluded from further analysis.

When the samples with 'good' IR-SF and C/P values were plotted against their resulting $\delta^{13}C$ and $\delta^{18}O$ data, there was no correlation found between any combinations of data (r-squared values were all below 0.03; n=111). Samples that had either IR-SF or C/P values in the good range (n=30) were plotted in the same manner and again show the same pattern of no correlation between bone crystallinity measures and subsequent $\delta^{13}C$ or $\delta^{18}O$ results (r-squared values ranged from 0.005 to 0.104). The observation that these data are not correlated (samples with only one 'good' measure of bone crystal preservation do not show any directional relationship to isotopic data) suggest that

samples that have at least one of the bone crystallinity measures in the 'good' range should be included in subsequent analysis of the isotope data, bringing the total sample size for bone apatite data discussed below to n=141.

Results and Discussion

One of the issues that stable isotope analysis grapples with is the difference between statistical significance and isotopically meaningful difference. I recognize that the isotope ratio data produced for any singular sample is related primarily to its biogenic chemical content when it is well preserved, but variables such as sample heterogeneity, chemical preparation methods, and analytical equipment also contribute to the isotopic variation that may be seen within a sample. In order to assess sample heterogeneity and preparation effects, repeat samples were analyzed and various difference measures were calculated.

For bone collagen samples, 48 Tibanica samples were analyzed in duplicate. The average difference between sample measurements for $\delta^{13}C$ is 0.2‰, with a range of 0.0 to 0.5‰ difference. The average difference between sample measurements for $\delta^{15}N$ is 0.2‰, with a range of 0.0 to 0.6‰ difference. Taking the most conservative estimate of variation, this study requires a minimum threshold of difference of 0.5‰ for $\delta^{13}C$ and 0.6‰ for $\delta^{15}N$ for differences in bone collagen data to be considered meaningfully different (the upper range of deviation observed for both isotopes). Nineteen dentin collagen samples were analyzed in duplicate. The average difference between sample measurements is 0.1‰ for $\delta^{13}C$, with a range of 0.0 to 0.3‰ difference in measurements on repeat samples. The average difference between sample measurements is 0.1‰ for $\delta^{15}N$, with a range of 0.0 to 0.3‰ between measurements on repeat samples. Therefore, this project requires a minimum difference of 0.3‰ in $\delta^{13}C$ and 0.3‰ for $\delta^{15}N$ in dentin collagen to be considered meaningfully different.

Nineteen bone apatite samples were analyzed in duplicate. The average difference between sample measurements is 0.2‰ for $\delta^{13}C$, with a range of 0.0 to 0.8‰ difference in measurements on repeat samples. Thirty-one enamel samples were analyzed in duplicate. The mean difference between sample measurements is 0.1‰ for $\delta^{13}C$, with a range of 0.0 to 0.6‰ difference in measurements on repeat samples. Therefore, this project requires a minimum threshold of 0.8‰ difference in $\delta^{13}C$ bone apatite data and 0.6‰ in $\delta^{13}C$ enamel apatite data to be considered meaningfully different.

Recent work by Pestle and collaborators (2015b) has proposed "minimum meaningful difference" (MMD) threshold values for various isotopic measurements when comparisons are being made between studies from different laboratory settings. The authors propose a minimum difference of 0.6‰ for $\delta^{13}C$ collagen, 0.9‰ $\delta^{15}N$ collagen, and 1.2‰ $\delta^{13}C$ apatite to aid in distinguishing isotopic data that is meaningfully different taking into account sample heterogeneity, preparation methods, and mass spec analytical differences (Pestle et al., 2015b). Here I report statistically significant differences and my discussion will emphasize those differences that are considered isotopically meaningful according to our project's established internal variation measures noted above.

Prehistoric Food Isotopes: Faunal Results

In order to contextualize the human dietary data presented we need to first understand the range of foods that may have been consumed and their associated

chemical signatures. Modern plants (n=24 species) and a small sample of zooarchaeological samples from the Tibanica site (n=6) were analyzed for their isotopic composition to provide a comparative reference collection. The modern plants and archaeological animals studied are not a comprehensive representation of Muisca foods, but these samples do provide preliminary baseline data for us to use and are listed in Tables 3.1 and Appendix A.

Table 3.1: Tibanica archaeological faunal samples analyzed for stable isotope data

SAMPLE	% N	% C	C/N atomic	δ^{15}N bone collagen (‰)	δ^{13}C bone collagen (‰)	δ^{13}C bone apatite (‰)	δ^{18}O bone apatite (‰)
Deer #1_*Odocoileus*	15.2	43.1	3.3	5.4	-18.3	-10.0	-5.0
Deer #2_*Odocoileus*	14.9	43.1	3.4	5.4	-17.9	-10.1	-7.0
Dog_*Canis familiaris*	16.0	47.6	3.5	8.2	-16.2	-11.5	-7.6
Bird #1	16.1	48.7	3.5	9.0	-9.9	-3.8	-6.0
Bird #2	16.2	49.5	3.6	5.9	-15.2	-10.3	-7.6
Guinea Pig_*Cavia porcellus*	12.0	35.2	3.4	4.6	-20.3	-8.3	-7.4

While interpretation of the faunal samples is limited due to small sample size, this preliminary data does indicate a wide-range of values across the different species (Figures 3.1 and 3.2). Early colonial documents indicate that deer were considered a special food and may have been restricted to only those individuals in positions of high power. The two deer samples (*Odocoileus*) have δ^{13}C values around -18‰ (corresponding to a C_3-plant based diet around -23‰) and δ^{15}N around 5‰, values that are within the range we expect to see for this genus which is known to primarily be a C_3 plant consumer (White et al., 2001). Other studies of *Odocoileus*, especially in Central America and Mesoamerica, have documented archaeological deer samples regularly consuming crops including maize (a C_4 plant), and are often seen as pests by farmers (Linares, 1976; Emery et al., 2000). The Tibanica data suggest these two deer consumed diets dominated by C_3 plants with a very small input from C_4 plants (likely from maize consumption), as a pure-C_3 plant diet would have slightly more negative δ^{13}C bone collagen values.

The guinea pig sample (*Cavia porcellus*) also shows a negative δ^{13}C value at -20.3‰ and a low δ^{15}N value of 4.6‰, indicating a diet dominated by C_3 plants. Guinea pigs are a common protein source in the Andes and are easily kept in pens (Miller, personal observation). These rodents often have diets reflecting the scraps from human meals, though they could be purposefully fed particular foods as fodder (see Finucane et al., 2006). If guinea pigs were fed by Tibanica peoples' meal scraps then it is clear that the scraps this individual rodent consumed were all C_3 plants such as potatoes, yuca, beans, squash, and quinoa. Finucane and co-authors (2006) found a large range of C and N isotope values for *Cavia porcellus* samples from the Wari site of Conchopata (Middle

Horison, Peru), with a range of -18.6 to -6.4‰ for $\delta^{13}C$, and 7.4 to 10.3‰ for $\delta^{15}N$. Further study of a larger number of *Cavia* samples from Tibanica and other Muisca sites will aid in clarifying if guinea pigs were specifically foddered on C_3 plants or if this animal is unusual compared to other guinea pigs (it is possible this animal lived during a period where C_3 plants were largely being harvested/consumed, and therefore reflects seasonal diet of humans).

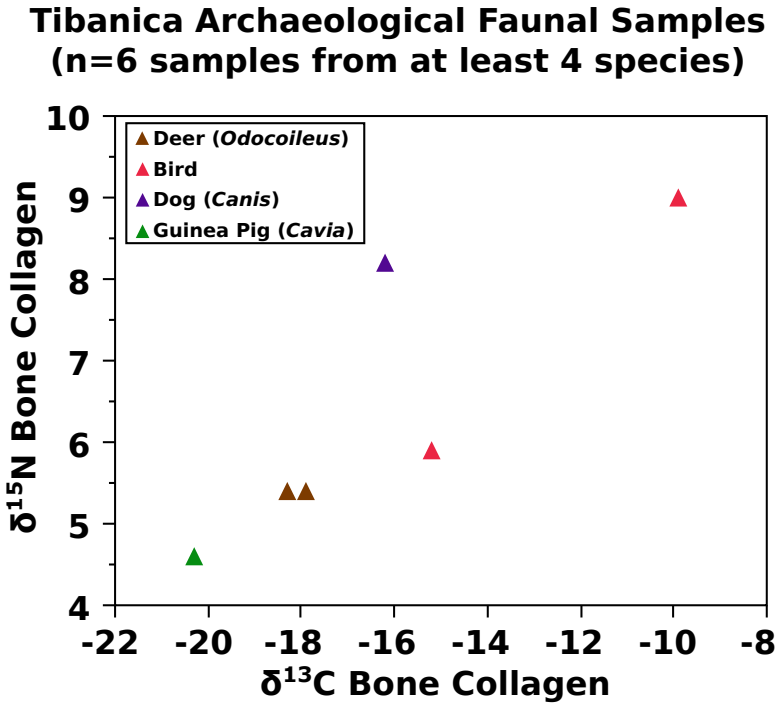

Figure 3.1: Bone collagen $\delta^{13}C$ and $\delta^{15}N$ data for Tibanica faunal samples (skewed towards protein portions of diet). Two deer, one guinea pig, one dog, and two bird samples were analyzed and show a large range of carbon and nitrogen isotopic values.

The dog sample (*Canis*) has a $\delta^{13}C$ of -16.2‰ and $\delta^{15}N$ of 8.2‰. Dogs are omnivorous and often receive leftovers from human meals, therefore we may expect dog samples to be similar to human isotope data. In this case the dog carbon data is significantly more negative than the mean human bone collagen data (see below), indicating the dog was fed more C_3 foods and proteins consuming C_3 plants (for example, guinea pig). If the dog was eating leftovers from human meals we would expect its value to be more positive for $\delta^{13}C$ (see below discussion of human diets). The $\delta^{15}N$ dog value is also about 1 per mil lower than the average human value, suggesting the dog ate proteins from lower trophic levels or consumed slightly less protein in general than the Tibanica peoples.

The bird samples (n=2) are very different from each other, with one bird consuming mostly C_4 or aquatic resources, while the other was consuming a mixture of C_3 and C_4 resources. The bird with the more positive $\delta^{13}C$ values could have a diet that relied on C_4 plants but may also have consumed aquatic resources that mimic C_4-type

carbon signatures. Work by Miller et al. (2010) demonstrated that aquatic plants and fish from the freshwater Lake Titicaca (Bolivia/Peru) have carbon isotope signatures enriched in ^{13}C, such that their carbon isotope data appears similar to terrestrial C_4 plant values (see Miller et al., 2010 for further details). These different bird isotope values could reflect a number of things – different bird species consuming different diets, or migrating birds consuming different diets due to environmental differences (aquatic versus terrestrial resources), domesticated versus wild bird dietary patterns, and more. Importantly it shows the range of bird diets may be very large and further sampling of diverse species is required to gain better knowledge of intra-species dietary patterns for these avifauna.

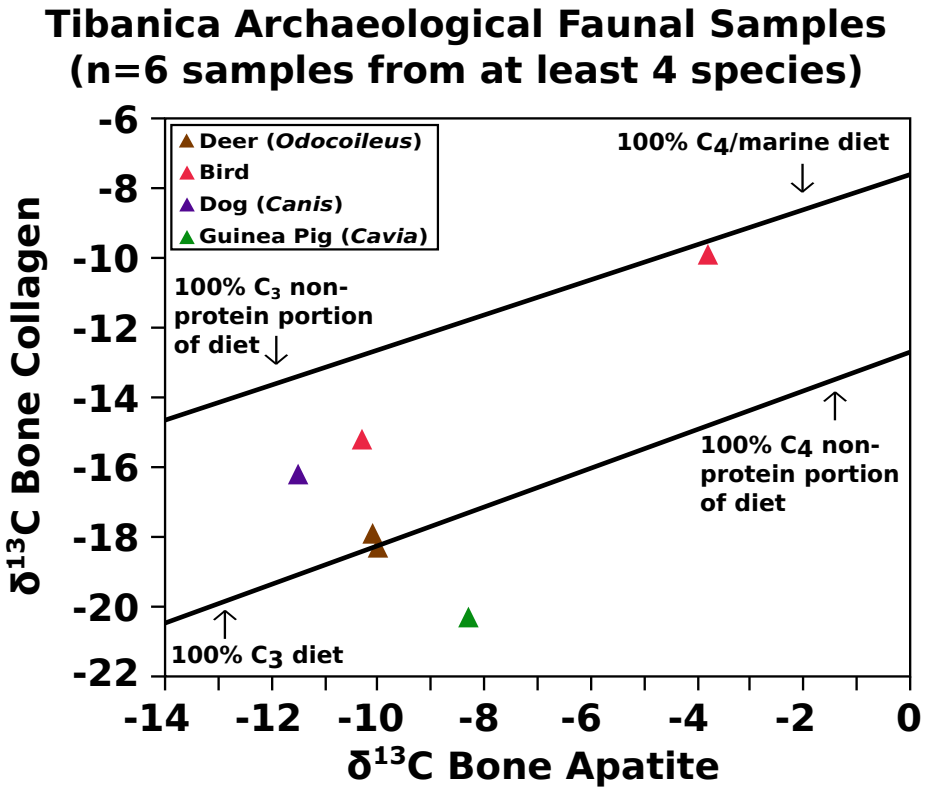

Figure 3.2: Bone apatite $\delta^{13}C$ and bone collagen $\delta^{13}C$ for Tibanica faunal samples (comparing total dietary carbon to carbon from protein sources). Data are plotted with regression lines from Froehle et al., (2010) to indicate dietary composition (arrows point to: 100% C4/marine diet; 100% C4 non-protein portion of diet; 100% C3 non-protein portion of diet; 100% C3 diet). $\delta^{13}C$ bone apatite is approximately 10‰ more positive than $\delta^{13}C$ diet and $\delta^{13}C$ bone collagen is approximately 5‰ more positive than $\delta^{13}C$ diet.

Work by Froehle and colleagues (2010) allows us to visualize the relationship between carbon from overall dietary sources (apatite carbonate) and carbon derived from protein sources (collagen carbon). Both bone carbon data sets are plotted with two regression lines that indicate the relationship of C_3 and C_4/aquatic resources. The regression lines are derived from animals raised on diets of known isotopic composition (Froehle et al., 2010). When we plot the faunal samples with these regression lines we see

that most of the animals cluster in the C_3 area of the graph, with only one bird predominantly feeding from C_4/aquatic isotopic resources (Fig 3.2, above). Taken together, the faunal data show a wide range of isotopic values that could influence human tooth and bone chemistry depending on which animals are consumed, and what proportion of the diet they regularly constitute. These data will provide a preliminary comparison for our human dietary data but are by no means intended as a comprehensive examination of zooarchaeological isotope data for this Tibanica community or for the Muisca. Future work will expand on the number and range of faunal species analyzed for isotope data.

Prehistoric Food Isotopes: Floral Results

Modern plants were collected from a farm in Tequendama, Colombia near the site of Tibanica. There were 54 samples analyzed for $\delta^{13}C$ and $\delta^{15}N$ data which covered 24 species of plants (many plants were sampled for multiple tissues, see Appendix A and Figure 3.3). Modern plants are depleted in ^{13}C due to the burning of fossil fuels and industrialization processes causing carbon isotope ratios to change within the atmosphere (called the Suess effect, see Yakir, 2011). Therefore, modern plant $\delta^{13}C$ values are about 1.5‰ more negative than those same plants' $\delta^{13}C$ data would have been in the prehistoric environment (Keeling, 1979; Yakir, 2011). The modern floral data presented here has not been corrected for the Suess effect. It is clear that of the plants sampled, the only C_4 plant is *Zea mays* while all other plants use the C_3 photosynthetic pathway. The plant data reveal a very large range of nitrogen values, from -1.9 to 13‰, showing the highly variable nature of plant nitrogen cycling and the complexity of interpreting trophic positions from nitrogen isotope data alone (Szpak et al., 2013; Szpak, 2014).

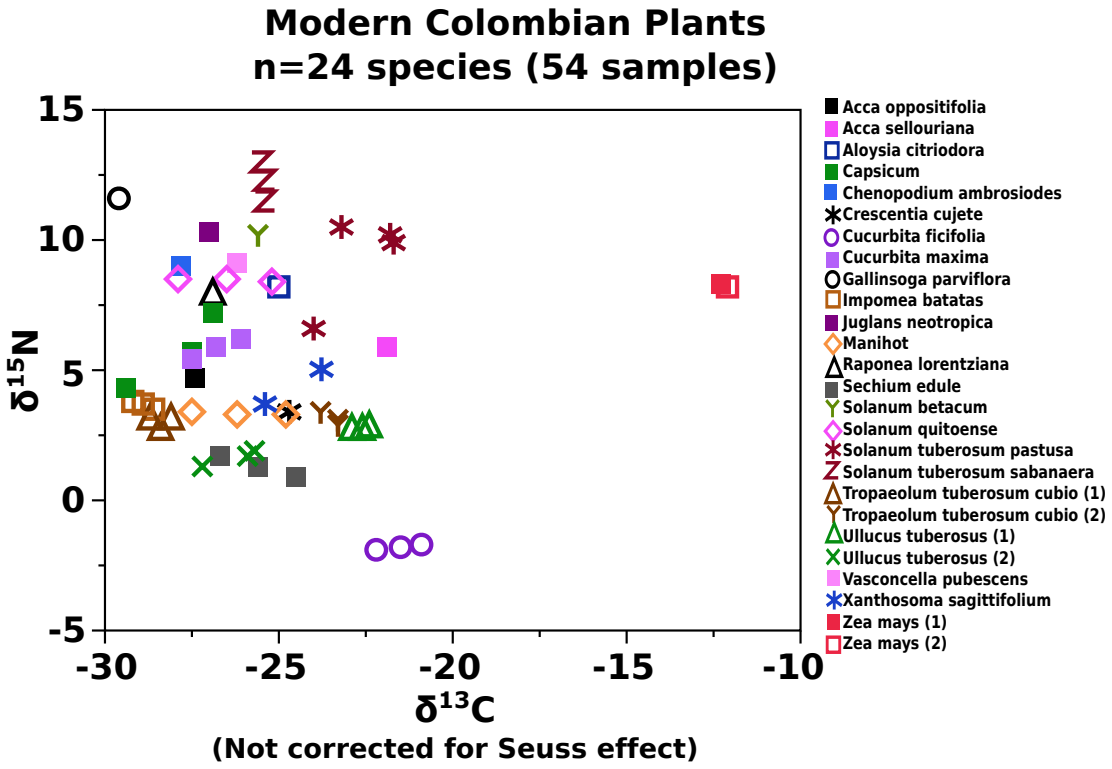

Figure 3.3: Modern plant samples $\delta^{13}C$ and $\delta^{15}N$ data. Plants were collected from a farm in Tequendama, Colombia near the Tibanica archaeological site. Twenty-four plant species are represented by fifty-four samples including comparisons of a single plant across multiple tissues (i.e. tuber skin, tuber starch, whole tuber). The $\delta^{13}C$ data has not been adjusted by +1.5‰ to account for modern climatic carbon shifts, called the Suess effect. Therefore, if these same plants were grown in ancient times they would be approximately 1.5‰ more positive for their $\delta^{13}C$ data.

Of particular interest is the range of variation in foods that are thought to have been important crops, for example *Zea mays* and the tubers (*Solanum*, *Tropaeolum*, *Ullucus*). Many plants were partitioned into various tissues so as to understand the variability in isotopic composition. For example, many tubers were separately sampled for the skin, starch, and then a combined sample with both parts (see Appendix A, Fig 3.3). It is interesting to note that most of the nitrogen of the potato is located in the skin of the *Solanum* tubers and little to no nitrogen is in the storage tissue (starch). Therefore, diets dominated by peeled potatoes would only have the chemical influence of carbon as little to no nitrogen would be coming from the potato starch. There is also a significant amount of variation for both carbon and nitrogen stable isotope data for the various tubers sampled here. All the tubers are C_3 plants but their $\delta^{13}C$ range spans over 7‰ while the $\delta^{15}N$ range is over 11‰; the *Solanum* genus has the highest $\delta^{15}N$ values while the *Ullucus* genus has the lowest.

This study also reports isotope data from a number of Andean plants that may have been consumed in smaller proportions such as fruits, nuts, and herbs used to flavor dishes. All of these are C_3 plants, but they do show a large range for $\delta^{15}N$ values, such as the Andean walnut (*Juglans*) with a very high $\delta^{15}N$ of 10.3‰, and the tomate de arbol (*Solanum betacum*) with a $\delta^{15}N$ value of 10.2‰. The large variation in $\delta^{13}C$ and $\delta^{15}N$ for the plants I report here complicate interpretation of human dietary data. Some of the

complexity may be resolved with further studies of these complex ecological relationships and advances in isotopic modeling, while further resolution will come with study of additional lines of evidence from the site of Tibanica and other Muisca settlements (via archaeobotanical data, archaeofaunal data, ceramic analyses, etc).

Overall Adulthood Diet

Of the 199 Tibanica individuals sampled, 168 had bone collagen that was well-preserved (had C/N values within the accepted range), and therefore were included for statistical analysis and discussion (n = 68 females, 82 males, 18 ambiguous or indeterminate; Appendix B; Figure 3.4). Within the entire Tibanica sample (n=168) the mean $\delta^{13}C$ is -12.0‰ (st dev = 1.2‰; min = -15.1‰, max = -8.2‰). The range of $\delta^{13}C$ values covers 7‰ per mil indicating that diets were not homogenous within this community and that a range of dietary variation is observed, potentially reflecting differential access and individual taste preferences. The average bone collagen carbon data corresponds to a diet averaging -17‰, suggesting regular consumption of both C_3 and C_4 foods. The heterogeneity of the carbon data indicates that dietary differences were consistent enough to be noted in bone chemistry, suggesting long-term patterns of food consumption that separated people along some kind(s) of variable(s).

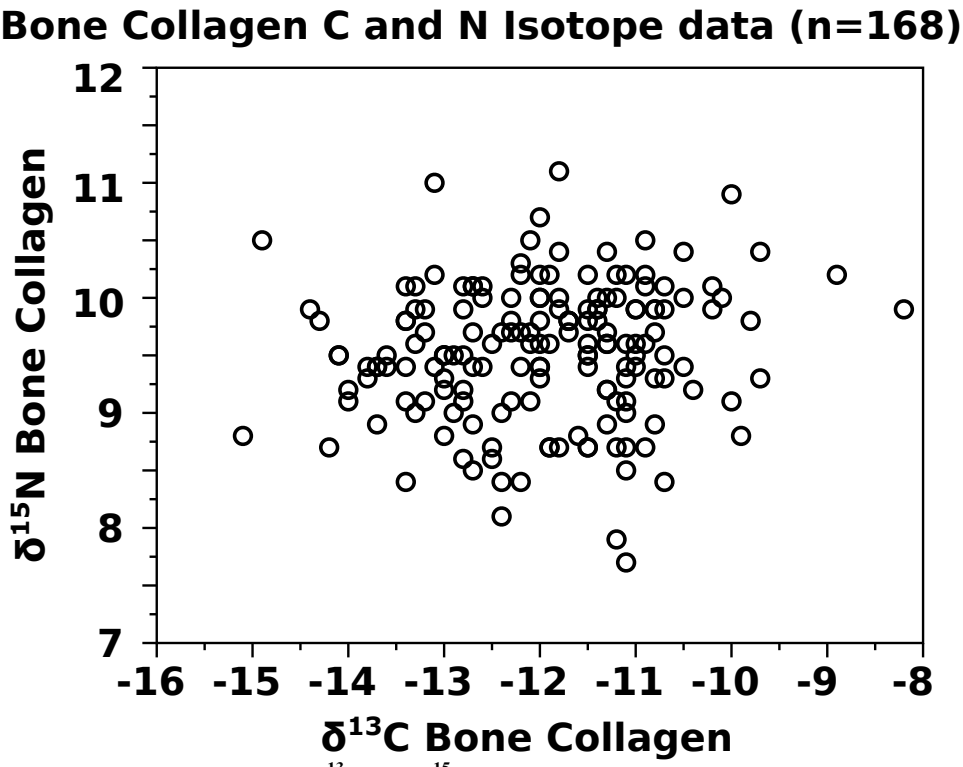

Figure 3.4: Tibanica bone collagen $\delta^{13}C$ and $\delta^{15}N$ data (n=168). Bone collagen isotopic data represents the average diet of the decade preceding death and is skewed towards protein sources. Bone collagen $\delta^{13}C$ is approximately 5‰ more positive than dietary $\delta^{13}C$.

The mean bone collagen $\delta^{15}N$ is 9.5‰ (st dev = 0.6‰, min = 7.7‰, max = 11.1‰) suggesting differential access to proteins and potentially consumption of proteins from trophic levels. As mentioned above, bone collagen preferentially acquires amino acids from protein-rich foods (usually thought to be from animal sources in the diet, but this could include legumes, quinoa, or other plants). Given the range of nitrogen values observed in the modern plant reference collection we cannot rule out that some of these plants may have been contributing carbon and nitrogen to bone collagen production. However, we also know that animals were consumed by Tibanica peoples so we assume that the majority of amino acids used for building bone collagen would be derived from these meat sources. Therefore, given the range of nitrogen isotope values for the Tibanica bone collagen samples, we see some individuals with more plant-based diets on the lower end of the nitrogen range, while others who show the highest values may have consumed more animal-based proteins. Some individuals with very negative $\delta^{13}C$ values and lower $\delta^{15}N$ values were likely consuming a greater proportion of meats that were C_3 plant consumers (possibly deer, guinea pigs, dogs, and others). Other individuals have very positive $\delta^{13}C$ values indicating the meats they ate may have consumed C_4 plants (possibly some animals were foddered with C_4 plants), consumed aquatic resources (such as birds), or were aquatic animals (such as fish).

The average $\delta^{13}C$ bone apatite is -6.6‰ (st dev = 0.9‰, min = -9.5‰ and max = -4.1‰), corresponding to an average dietary $\delta^{13}C$ of about 16.3‰ (using 9.7‰ as the difference between bone apatite and diet, average value from pig/rodent models, see (Ambrose and Norr, 1993; Tieszen and Fagre, 1993; Somerville et al., 2015). This mean $\delta^{13}C$ bone apatite value is intermediate between a pure C_3 or pure C_4 diet, indicating that the average Tibanica person was consuming regularly from both of these food bases, and that maize was a common part of their diet.

By combining bone collagen and bone apatite isotopic data we can better parse overall diet from protein contributions. Figure 3.5 shows the relationship between total dietary carbon to carbon from dietary proteins, plotted with the dietary modeling lines from Froehle et al. (2010). From the x-axis (Figure 3.5) bone apatite $\delta^{13}C$ data we see that both C_3 and C_4 plants are important and widely consumed. The clustering of most people in the center of the graph around -7‰ indicate that the average person consumed heavily from maize and the C_3 plant food groups, likely in close to equal ratios. However, there is a range of diets represented, as we see a number of people who ate mostly C_3 foods (those few individuals around -9‰) while others consumed great amounts of maize (those whose $\delta^{13}C$ bone apatite is around -4‰).

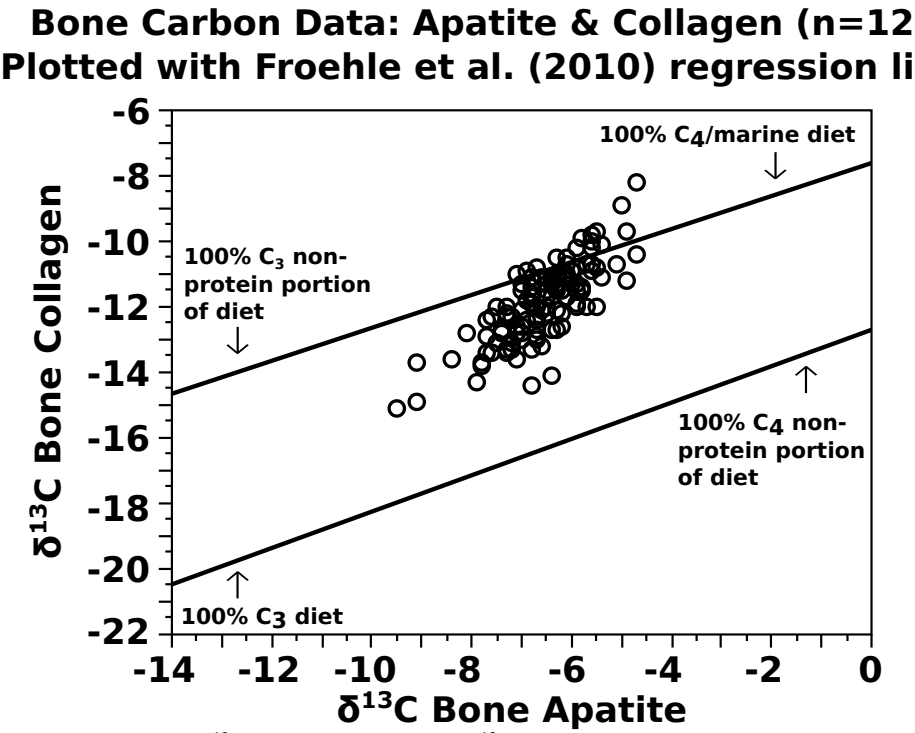

Figure 3.5: Bone apatite $\delta^{13}C$ and bone collagen $\delta^{13}C$ for Tibanica samples, comparing total dietary carbon to carbon from protein sources, n=120 individuals. Plotted with regression lines from Froehle et al., (2010) to indicate dietary composition (arrows point to: 100% C4/marine diet; 100% C4 non-protein portion of diet; 100% C3 non-protein portion of diet; 100% C3 diet). $\delta^{13}C$ bone apatite is approximately 10‰ more positive than $\delta^{13}C$ diet and $\delta^{13}C$ bone collagen is approximately 5‰ more positive than $\delta^{13}C$ diet.

From the bone collagen (y-axis; Figure 3.5) data we observe that most people are clustered around the C_4 protein line while others are more intermediately located between the two lines. Those people that are close to or on the C_4 protein line were obtaining most of their dietary protein from C_4 or aquatic foods. These C_4 proteins could have been plant-based, but maize is thought to be the only widely consumed C_4 plant and it is a poor source of dietary protein (Mitchell et al., 1952; Young and Pellett, 1994; Friedman, 1996; Cordain, 1999). The amino acid lysine, found in maize, is more accessible once it is fermented, such as in *chicha* beer (Hamad and Fields, 1979; Umoh and Fields, 1981; Sangwan et al., 2014; Somerville et al., 2015) so this may have been an important Muisca food source that we would not commonly associate with protein consumption. Animals may also have diets based on C_4 plants and therefore consumption of those animals by humans would lead to a C_4 protein signature. The archaeological faunal samples from Tibanica suggests that birds may have been an important dietary protein for many individuals in Tibanica (one of the two birds sampled has very positive $\delta^{13}C$ values, that may be related to their consumption of C_4 plants or aquatic resource consumption). The other faunal samples analyzed (deer, guinea pig, dog, and another bird) have values that indicate their diets were mostly composed of C_3 plants, however small sample size precludes conclusion of whether this was the norm. The humans that are closer to the C_3 protein line may have been consuming more of those animals for their dietary protein (such as deer, dog, guinea pigs). These data suggest that Tibanica people had access to a

variety of plant and meat foods and that there were different dietary patterns within the population, likely reflecting differential access and personal tastes.

Between Burial Groups

The individuals recovered from the archaeological site of Tibanica were found in four distinct burial groupings (see Figure 2.2). I tested for differences between the burial groupings (sexes and age groups combined) across all isotopic data, to see if any burial groupings were significantly different from one another. I found no significant isotopic differences between burial groups for any of the adulthood dietary isotope measures.

Adulthood Dietary Differences by Status, Sex, Age

Status

The isotopic data do not support the hypothesis that people of high status had significant dietary differences within this community. We do not see any statistically significant or isotopically meaningful difference in $\delta^{13}C_{\text{bone collagen}}$ or $\delta^{13}C_{\text{bone apatite}}$ between people buried with or without durable grave goods (Figures 3.6 and 3.7). People buried with grave goods do have a slightly higher average $\delta^{15}N$ that is statistically significant but is not likely to be an isotopically meaningfully different. The mean $\delta^{15}N$ for those with grave goods is 9.8‰ and the mean $\delta^{15}N$ for those without is 9.5‰ (difference of 0.3‰; Wilcoxon rank sums p-value is 0.0036). It is important to note that the individuals having the very highest $\delta^{15}N$ values (around 11‰) are people who were buried with durable grave goods. These four individuals are identified as one male, one female, and two individuals whose sex could not be determined. These few people are significantly and meaningfully different from the majority of the Tibanica people who have the lower $\delta^{15}N$ values. It is particularly striking if we were to compare the two extremes for protein access, where isotope values are reflecting starkly different consumption. In those cases, higher status may have conferred better, consistent access to protein sources in comparison to the individuals with very low $\delta^{15}N$ values who may have had less protein in their diet overall.

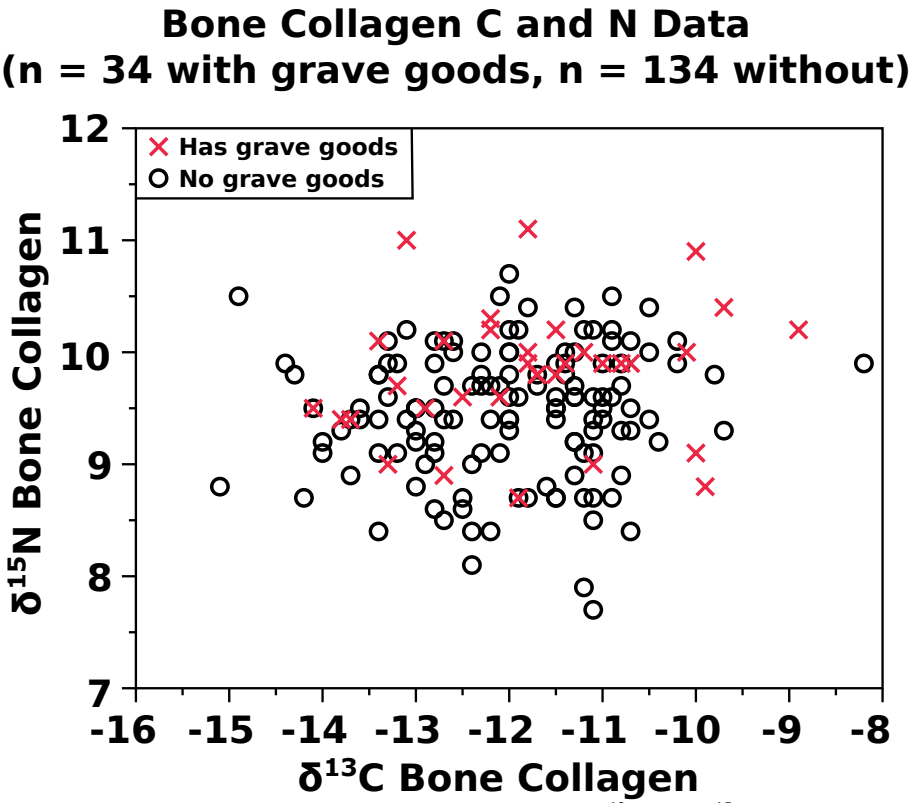

Figure 3.6: Tibanica social status is plotted with bone collagen $\delta^{13}C$ and $\delta^{15}N$ data (n=168). Bone collagen $\delta^{13}C$ is approximately 5‰ more positive than dietary $\delta^{13}C$. Individuals of high social status (presence of durable grave goods) are marked with a red x (n=34), those individuals without burial goods are marked with open circles (n=134). There is no difference in $\delta^{13}C$ for high/low status individuals, but there is a statistically significant difference in $\delta^{15}N$ (those with burial goods may have consumed slightly more meat than others). Bone collagen isotopic data represents the average diet of the decade preceding death but is skewed towards protein sources.

These data indicate that on the whole, higher status people did not have regular access to foods that set them apart from others. Higher status individuals may have occasionally been eating more of certain highly valued foods, such as during special/feasting events, but this was not common enough to affect their average dietary chemistry. If deer meat had been restricted to highly ranked peoples, as the historical documents suggest, then we would expect to see those with high status to have dietary data indicating greater C_3 protein consumption, which we do not see. Also, if maize was a privileged food/drink then we would again expect to see those of high status to be clustered more towards C_4 plant food dietary values, which we do not observe (high status individuals cover essentially the same range of $\delta^{13}C$ and $\delta^{15}N$ as those without grave goods). These results were unexpected given that most Muisca research has emphasized the role of social status and it is thought that dietary privilege might accompany higher social status roles.

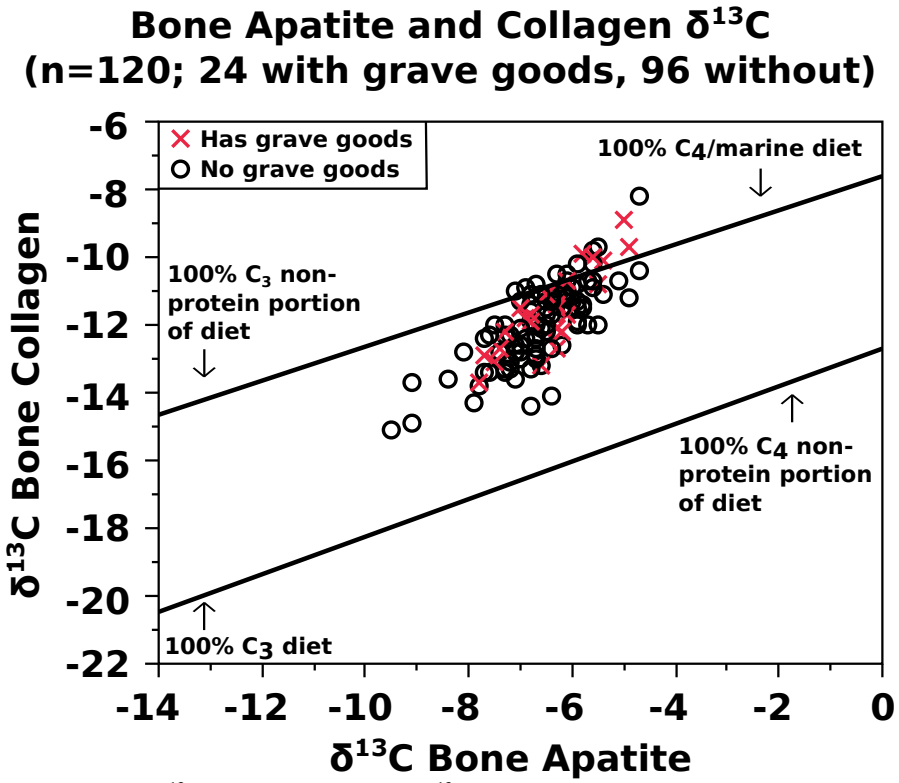

Figure 3.7: Bone apatite $\delta^{13}C$ and bone collagen $\delta^{13}C$ for Tibanica samples with individuals of high social status marked by a red x (n=24) and individuals without burial goods marked with an open circle (n=96). This graph compares total dietary carbon to carbon from protein sources, and the data are plotted with regression lines from Froehle et al., (2010) to indicate dietary composition (arrows point to: 100% C4/marine diet; 100% C4 non-protein portion of diet; 100% C3 non-protein portion of diet; 100% C3 diet). $\delta^{13}C$ bone apatite is approximately 10‰ more positive than $\delta^{13}C$ diet and $\delta^{13}C$ bone collagen is approximately 5‰ more positive than $\delta^{13}C$ diet. No significant differences are observed between high and low status individuals' diets for either carbon measurement.

Sex

While the relationship between status and diet is not significant for most individuals in Tibanica, the relationship between sex and diet is striking (Tables 3.2 and 3.3). From the isotopic data it is evident that there are statistically significant and meaningful differences between female and male diets (Figures 3.8, 3.9, 3.10). While status appeared to only confer a small number of people with greater access to proteins, there are more apparent patterns of dietary divisions between males and females. The most significant difference is in the bone collagen $\delta^{13}C$ data. Most females have more negative $\delta^{13}C_{\text{bone collagen}}$ values in comparison to males who have more positive $\delta^{13}C$ values. Within females the average $\delta^{13}C_{\text{bone collagen}}$ is -12.5‰ (st dev = 1.0‰, min = -14.3‰ and max = -10‰) while within Tibanica males the average $\delta^{13}C_{\text{bone collagen}}$ is -11.5‰ (st dev = 1.1‰, min = -15.1‰ and max = -8.2‰, has 4 outliers). The difference (1‰) between the average female and male $\delta^{13}C_{\text{bone collagen}}$ is both statistically significant (t-test p-value <0.0001) and meaningfully different, and suggests that overall, females consumed less C_4 foods (maize and/or C_4-type proteins) compared to males.

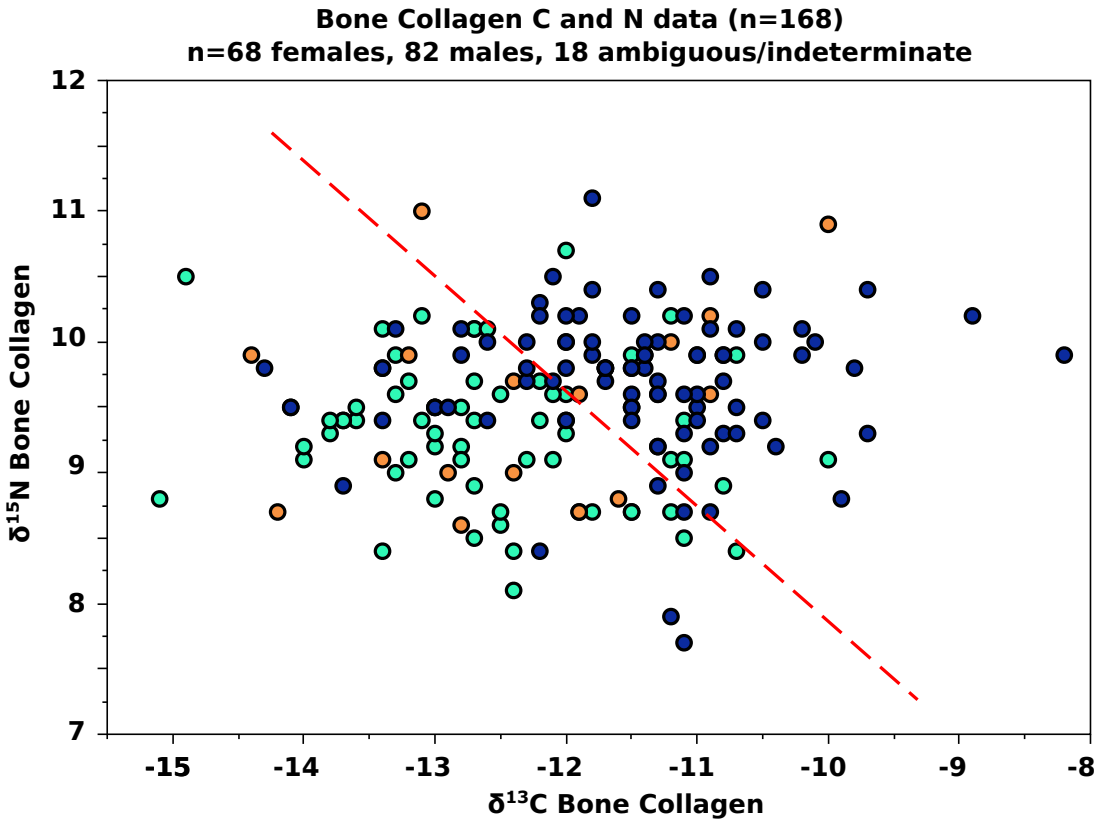

Figure 3.8: Tibanica bone collagen $\delta^{13}C$ and $\delta^{15}N$ data (n=168) are plotted with the variable of sex. Females are plotted as green circles (n=68), males are dark blue circles (n=82) and individuals who were ambiguous or indeterminate are plotted in orange (n=18). Bone collagen isotopic data represents the average diet of the decade preceding death and is skewed towards protein sources. A pattern of division between male and female diets can be observed for both $\delta^{13}C$ and $\delta^{15}N$, with a red dashed line indicating the general area where males and females diverge.

Table 3.2: Summary data for male and female dietary data across all tissue types and isotopic measurements (carbon, nitrogen, oxygen).

Tissue and Isotope Measured	FEMALES				MALES			
	n	mean	SD	SE mean	n	mean	SD	SE mean
Bone Collagen								
Carbon	68	-12.5	1	0.1	82	-11.5	1.1	0.1
Nitrogen	68	9.3	0.5	0.1	82	9.7	0.6	0.1
Bone Apatite								
Carbon	45	-6.9	0.9	0.1	77	-6.3	0.8	0.1
Oxygen	45	-8	0.9	0.1	77	-8	1.3	0.2
Tooth Enamel								
Carbon	58	-4.6	1.3	0.2	88	-4	1.3	0.1
Oxygen	58	-7.6	1	0.1	88	-7.7	0.8	0.1
Tooth Dentin								
Carbon	60	-12.1	1.3	0.2	90	-11.3	1.3	0.1
Nitrogen	60	10.3	0.7	0.1	90	10.2	0.6	0.1

The average male $\delta^{15}N_{bone\ collagen}$ value is 9.7‰ (st dev = 0.6‰, min = 7.7‰, max = 11.1‰), which is higher than the average female $\delta^{15}N_{bone\ collagen}$ at 9.3‰ (st dev = 0.5‰, min = 8.1‰, max = 10.7‰). Again this reflects a small difference in group diet. While this difference is statistically significant (Wilcoxon rank sums p-value is <0.0001), the difference between the means (0.4‰) does not quite meet this project's threshold for meaningfully different (0.6‰). However, the graphical representation of the bone collagen data (Figure 3.8) shows a clear pattern of differentiation between males and females for both C and N isotope data. Most of the females are shifted towards the lower left portion of the graph while the males are more oriented towards the upper right. However, there is not a uniform pattern. There are a number of individuals who are outliers relative to their sex-group. For example, a few males have very negative $\delta^{13}C$ values while a few females have more positive $\delta^{13}C$ values, and a couple of males have very low $\delta^{15}N$ values while a couple females have quite high $\delta^{15}N$ values. These individuals are interesting as they do not follow the pattern of their peers and future contextual study of these specific individuals will attempt to address why these people are outliers: do they just have different taste preferences or are there other biological or social variables that are influencing their dietary patterns? Additional research may be able to reveal other variables influencing these unusual individuals' dietary data, while aspects such as personal taste preferences will likely always be elusive in archaeological work but should be recognized as potentially playing an important role in dietary patterns. Overall, the bone collagen data suggest there are general patterns that differentiate females and males through diet, particularly related to access to C_4-type foods.

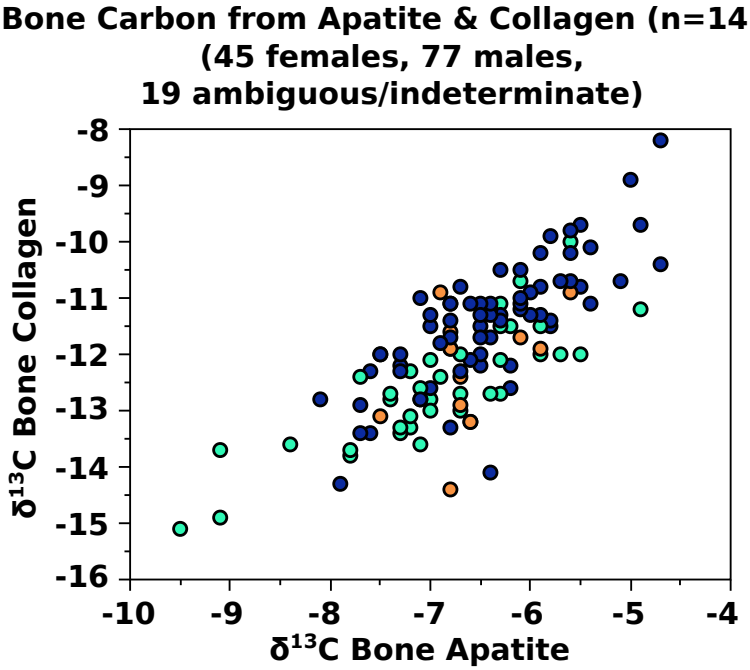

Figure 3.9: Bone apatite $\delta^{13}C$ and bone collagen $\delta^{13}C$ for Tibanica samples with females noted by green circles (n=45), males noted as dark blue circles (n=77), and ambiguous/indeterminate individuals represented by orange circles (n=19). This graph shows a pattern of male diets shifted up and to the right (more positive for both collagen and apatite $\delta^{13}C$) while females tend to be shifted down and to the right (more negative $\delta^{13}C$ values).

When bone apatite $\delta^{13}C$ is plotted with $\delta^{13}C_{bone\ collagen}$, we can again see the effects of differential access to C_4 foods between the sexes (Figure 3.9). The average female $\delta^{13}C_{bone\ apatite}$ is -6.9‰ (st dev = 0.9‰, min = -9.5‰ and max = -4.9‰), while the average male $\delta^{13}C_{bone\ apatite}$ is -6.3‰ (st dev = 0.8‰, min = -8.1‰ and max = -4.1‰). The difference (0.6‰) is statistically significant between the sexes (t-test p-value <0.00029) but does not quite meet the threshold of 0.8‰ to be isotopically meaningfully different. However, it is again apparent that an important pattern emerges from the data as a whole, with males generally shifted up to the right on the dual-carbon graph (more positive values for both carbon isotope points) while females tend to be shifted down and to the left (more negative carbon isotope data).

Since $\delta^{13}C_{bone\ apatite}$ reflects total dietary carbon sources while $\delta^{13}C_{bone\ collagen}$ emphasizes dietary protein chemistry, we can compare these values to better understand the relationship between these different dietary inputs. Early modeling of dietary composition relied on simple end-member mixing models (Vogel and van der Merwe, 1977; Chisholm et al., 1983; Schwarcz et al., 1985; Schwarcz, 1991). From there, experimental work examining $\delta^{13}C_{diet}$, $\delta^{13}C_{bone\ collagen}$, and $\delta^{13}C_{bone\ apatite}$ worked to identify the contributions of proteins, carbohydrates and fats to each skeletal tissue. These projects revealed that the spacing between $\delta^{13}C_{bone\ collagen}$ and $\delta^{13}C_{bone\ apatite}$ ($\Delta^{13}C_{ap\text{-}coll}$) can indicate if dietary protein sources were enriched or depleted in carbon relative to the overall diet, or if the diet was relatively monoisotopic (Ambrose and Norr, 1993; Tieszen and Fagre, 1993; Ambrose et al., 2003). Differences between $\delta^{13}C_{apatite\text{-}collagen}$ that are greater than 4.4‰ indicate dietary proteins are more negative than the whole diet (so more C_3-feeding animals are being consumed as the protein source, see (Krueger and Sullivan, 1984; Ambrose and Norr, 1993; Ambrose et al., 2003). There is a range of $\Delta^{13}C_{ap\text{-}coll}$ for the Tibanica peoples, from 3.5‰ to 7.7‰ difference between the carbon values of these tissue types. The male mean $\Delta^{13}C_{ap\text{-}coll}$ is 4.9‰, while the female mean $\Delta^{13}C_{ap\text{-}coll}$ is 5.6‰. Therefore, the $\Delta^{13}C_{ap\text{-}coll}$ for Tibanica peoples suggest that the diets are dominated by C_4 plants and animal proteins that were foddered on C_4 plants or mimic a C_4-type signature (birds/aquatic species, see (Miller et al., 2010), with little protein input from C_3-feeding animals, though females may have consumed slightly more of those C_3 proteins. In other words, the Tibanica women probably ate more potatoes, yuca, beans, squash, and quinoa than then males did, but again these may have been just slightly different amounts. For comparison, Ambrose et al. (2003) report $\Delta^{13}C_{ap\text{-}coll}$ values of low status Cahokians as 13.5‰ while high status Cahokians $\Delta^{13}C_{ap\text{-}coll}$ spacing was 8.5‰, indicating very large differences in the types of dietary protein consumption for each status group (Ambrose et al., 2003). Therefore, the Tibanica data suggest that there is a *slight* difference in dietary protein sources for males and females, but not on the same level as has been observed in other populations. It is possible that differences in male and female consumption are therefore differences in quantity or frequency of consumption of particular proteins, with less influence from differences kinds of protein.

These calculations can be contrasted with another dietary protein estimation model developed by Pestle et al. (2015b). Their work produced an equation that utilizes the $\Delta^{13}C_{ap\text{-}coll}$ value and the $\delta^{13}C_{bone\ collagen}$ value for each individual to estimate the $\delta^{13}C$ value of the protein sources that produced those human skeletal values (error estimated at ±1.9‰ for each $\delta^{13}C_{protein}$ calculated). I calculated the predicted $\delta^{13}C_{protein}$ for Tibanica

people that had both $\delta^{13}C_{bone\ apatite}$ and $\delta^{13}C_{bone\ collagen}$ values (n = 120). The mean $\delta^{13}C_{protein}$ for all Tibanica samples is predicted to be -17.0‰ (st dev = 1.3‰, range is from -20.3‰ to -13.1‰; does not account for the associated equation error ±1.9‰). The mean $\delta^{13}C_{protein}$ for Tibanica females (n=43) was predicted to be -17.6‰ (range -19.7 to -15.1‰) and the Tibanica male (n=66) dietary protein $\delta^{13}C$ was predicted to be -16.5‰ (range -20.2 to -13.1‰; does not account for the associated equation error ±1.9‰). From these calculations we again see that female isotopic data reflect a slightly greater consumption of C_3 proteins (possibly guinea pigs, dogs, birds) though both sexes appear to have had a significant portion of dietary protein derived from C_4-type sources (maize, C_4-foddered animals, birds, aquatic species).

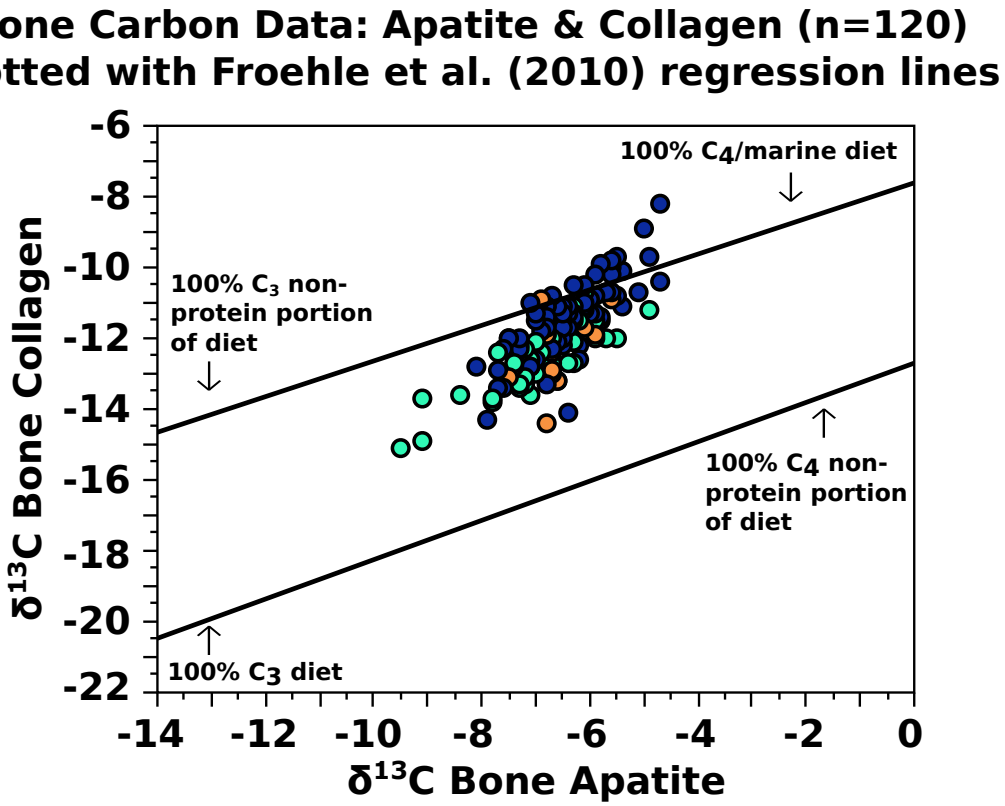

Figure 3.10: Bone apatite $\delta^{13}C$ and bone collagen $\delta^{13}C$ for Tibanica samples with females noted by a green circle (n=45), males noted as dark blue circles (n=77), and ambiguous/indeterminate individuals represented by orange circles (n=19). This graph compares total dietary carbon to carbon from protein sources, and the data are plotted with regression lines from Froehle et al., (2010) to indicate dietary composition (arrows point to: 100% C4/marine diet; 100% C4 non-protein portion of diet; 100% C3 non-protein portion of diet; 100% C3 diet). $\delta^{13}C$ bone apatite is approximately 10‰ more positive than $\delta^{13}C$ diet and $\delta^{13}C$ bone collagen is approximately 5‰ more positive than $\delta^{13}C$ diet. Male diets have more C_4 foods overall, including proteins that mimic a C_4 isotopic signature, while females are mostly shifted below the C_4 protein line.

When the $\delta^{13}C_{bone\ apatite}$ and $\delta^{13}C_{bone\ collagen}$ data are plotted with the Froehle et al. (2010) regression lines (Figure 3.10), the differential consumption patterns between the sexes are made visible – males are shifted towards greater C_4 consumption (both in terms of overall diet and related to protein access) compared to females (slightly less consumption of C_4-type foods). On the whole, Tibanica females are shifted down from the C_4 protein line while most males are on that line or even above it, in agreement with the $\Delta^{13}C_{ap\text{-}coll}$ spacing data and the predicted $\delta^{13}C_{protein}$ estimates. Therefore, we see that within the Tibanica community there is an important division between the sexes that is embodied through differential food access/consumption practices, especially related to maize and proteinatious foods. Males consumed a greater proportion of C_4 foods than females on a consistent basis, and while dietary patterns are quite heterogeneous, there is a unifying trend within males when it comes to C_4 food access. These foods would have likely been both maize and protein sources (based on the three forms of isotope data provided here). Men could have been consuming more maize (both as a food and as a beverage) and they also may have consumed more proteins with C_4-type signatures (perhaps more birds).

Overall, these isotopic results are similar to patterns observed in other Andean populations, with divisions between the sexes particularly marked by differential consumption of maize. Recent work by Somerville and colleagues (2015) found high amounts of maize consumption across both sexes within Tiwanaku colony groups located around the Moquegua valley during the Middle Horizon (AD 500-1000). The authors observed higher $\delta^{13}C$ values for male bone collagen and they suggest that this was a product of males consuming more maize than females, particularly in the form of *chicha* (Somerville et al., 2015). Interestingly, the Tibanica individuals have bone isotope values ($\delta^{13}C_{bone\ apatite}$, $\delta^{13}C_{bone\ collagen}$, $\delta^{15}N_{bone\ collagen}$) that are very similar to the Tiwanaku colonies studied by Somerville et al. 2015, but with Tibanica males and females showing significant differences across multiple isotope measurements.

Hastorf (1991) documented dietary change for the Sausa people of the Peruvian Andes (AD 1300-1550) before and after their incorporation into the Inca state. During earlier periods (Wanka II) the wealthier elites had more access to maize but after the Inca conquest (Wanka III) maize was more accessible, and both commoners and elites appear to have similar production and consumption of this crop (Hastorf, 1991). Additionally, male and female diets become more divergent after incorporation into the Inca empire, with a sub-set of the males consuming more maize and meat than females (Hastorf, 1991). Comparing the Tibanica sample to the Wanka III sample, we see that on the whole this Muisca community consumed significantly more maize than the Sausa people did, with a similar pattern of gendered access to maize, likely related to more *chicha* consumption by some of the male population. The Tibanica female mean $\delta^{13}C_{bone\ collagen}$ is -12.5‰, much more enriched than the Wanka III females $\delta^{13}C_{bone\ collagen}$ mean of -16.4‰, and the Tibanica male mean $\delta^{13}C_{bone\ collagen}$ of -11.5‰ is much higher than the Wanka III males $\delta^{13}C_{bone\ collagen}$ mean of -14.2‰ (Hastorf, 1991). These data suggest larger trends within pre-Columbian Andean communities where food practices are part of the daily activities that create and maintain gender roles.

Age

When we look at each sex separately and compare bone isotope data between the age-groups we see more significant differences (Table 3.3). Within both females and males there are declines in $\delta^{13}C_{\text{bone apatite}}$ and $\delta^{13}C_{\text{bone collagen}}$ across age groups, while there is very little change in $\delta^{15}N_{\text{bone collagen}}$ across age groups. For $\delta^{13}C$ data we see that the youngest individuals in each sex have the most positive values that then decline as people age, and importantly, this general trend is the same for both sexes. Specifically, there is a statistically significant difference between the young and middle age females, and the young and older aged females for both $\delta^{13}C_{\text{bone collagen}}$ and $\delta^{13}C_{\text{bone apatite}}$. For young versus middle age females the difference (0.8‰) in $\delta^{13}C_{\text{bone collagen}}$ (Fig 3.11) and $\delta^{13}C_{\text{bone apatite}}$ (also 0.8‰, Fig 3.12) are both statistically and meaningfully different (Wilcoxon rank sums each pair: p-value = 0.0006 for bone collagen, p-value = 0.0037 for bone apatite). Comparing the younger versus older females, the $\delta^{13}C_{\text{bone collagen}}$ and $\delta^{13}C_{\text{bone apatite}}$ data are statistically and meaningfully different, with younger females having higher carbon isotope values than older females. For the bone collagen $\delta^{13}C$ the difference between young and older female means is 1.4‰ between the group averages (Wilcoxon rank sums p-value = 0.0041) and the difference between bone apatite $\delta^{13}C$ is 0.9‰ (Wilcoxon rank sums p-value = 0.0372). Taken together, these carbon data indicate a substantial change in female diets across the life-course, with more C_4-type foods consumed earlier in life and then, as one ages, a woman consumes less of those foods (possibly supplementing the diet with other C_3 foods instead). This may indicate less C_4 consumption in terms of both maize (as a food and as a drink) and also protein sources that have a C_4/aquatic diet. We also must remember that young adulthood diet, bounded here as ages 18-29, is from bone tissue that is incorporating dietary information over at least a decade, so if one is age 25 at death, that means the diet is from at least age 15 until death, therefore we could have some effects of residual childhood diet which may reflect different eating habits than adulthood (though see below discussion of childhood diet).

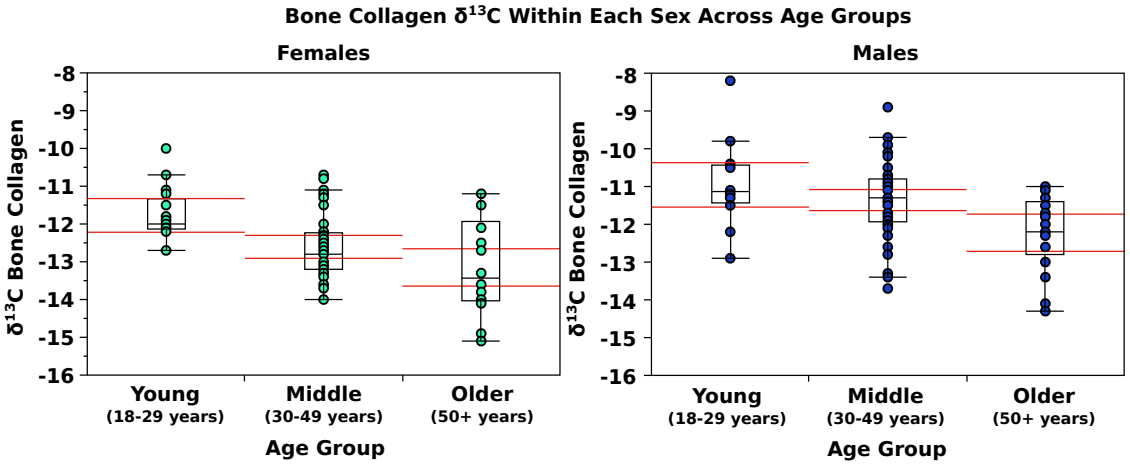

Figure 3.11: Bone collagen $\delta^{13}C$ plotted by sex and age (collagen emphasizes protein sources). Female data is plotted on the left graph (green circles) and male data on the right graph (dark blue circles). The red lines are the 95% confidence interval of the mean. Young individuals are aged 18-29 years old at death, middle aged individuals lived between 30-49 years, and older aged individuals lived 50+ years. A decline in bone collagen $\delta^{13}C$ is noted across the age groups within each sex, corresponding to a diet that has less C_4 –type food sources as an individual ages. Note the relatively steady decline for females across the age groups, and the more dramatic drop between middle and older age for males.

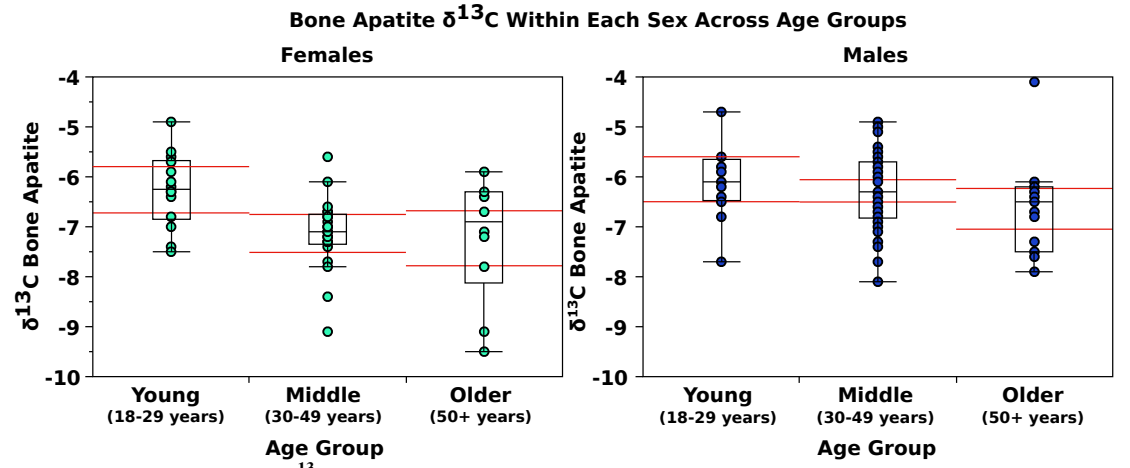

Figure 3.12: Bone apatite $\delta^{13}C$ plotted by sex and age. Female data is plotted on the left graph (green circles) and male data on the right graph (dark blue circles). The red lines are the 95% confidence interval of the mean. Young individuals are aged 18-29 years old at death, middle aged individuals lived between 30-49 years, and older aged individuals lived 50+ years. A decline in $\delta^{13}C$ is noted across the age groups within each sex, corresponding to a diet that has less C_4 –type food sources as an individual ages. Note the relatively steady decline for females across the age groups, and the more dramatic drop between middle and older age for males (though this is not a statistically-significant age-related change).

Tibanica males also show a similar pattern of decreasing $\delta^{13}C$ values with age. The mean $\delta^{13}C_{bone\ collagen}$ of young aged males is -11‰ which is statistically significantly more positive than the older age males mean $\delta^{13}C_{bone\ collagen}$ = -12.2‰ (Wilcoxon paired comparison p-value is 0.0078), and meaningfully different. The $\delta^{13}C_{bone\ apatite}$ values for

males also show a trend of decreasing across the age groups but this change does not reach statistical significance. Therefore, both the females and the males show an age-related change in eating habits which correspond to consuming less C_4-type foods as one ages. Interestingly there is no statistical difference with age for $\delta^{15}N_{bone\ collagen}$, values for both sexes tend to be very stable across adulthood, suggesting that access to protein sources does not change for adults as they age (Figure 3.13).

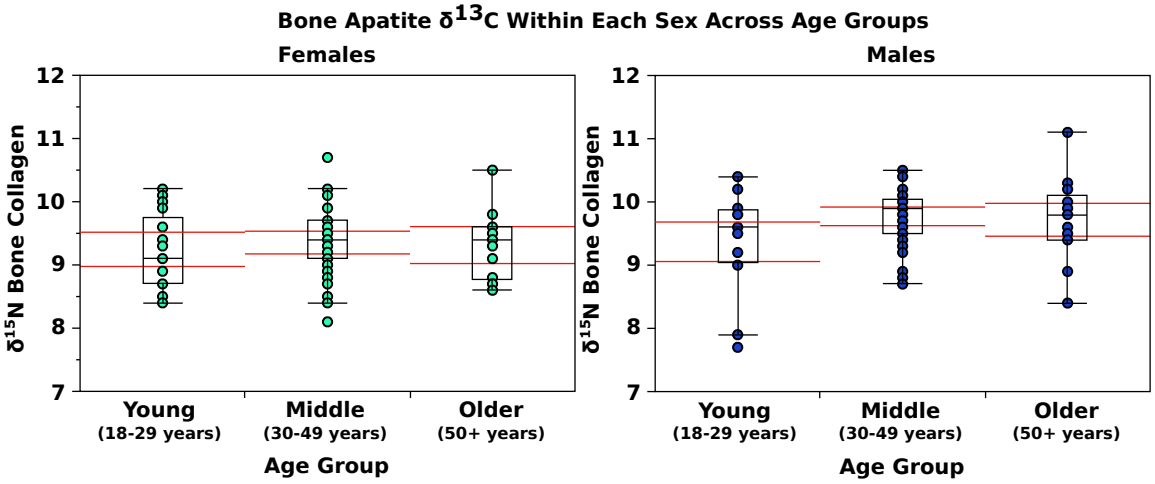

Figure 3.13: Bone collagen $\delta^{15}N$ plotted by sex and age (collagen emphasizes protein sources). Female data is plotted on the left graph (green circles) and male data on the right graph (dark blue circles). The red lines are the 95% confidence interval of the mean. Young individuals are aged 18-29 years old at death, middle aged individuals lived between 30-49 years, and older aged individuals lived 50+ years. No significant changes are noted for $\delta^{15}N$ data across adulthood for females or males, suggesting similar amounts and/or types of proteins for both sexes as they aged.

I hypothesize that the age-related decline in C_4-food consumption is caused by the effects that Tibanica dietary practices have on long-term dental health. Maize is a gritty food (particularly when processed on grinding stones), and also high in carbohydrates – two factors that are known to contribute to dental caries and ante-mortem tooth loss (Turner, 1978; Larsen et al., 1991; Lingstrom et al., 2000; Cucina and Tiesler, 2003). If Tibanica peoples' diets were high in maize (which they appear to have been for both sexes, but especially for males) then individuals could be effected by the dental issues that long-term maize consumption can cause. The Tibanica sample had a high prevalence of dental caries and ante-mortem tooth loss (see Chapter 2 of this dissertation; Langebaek et al., 2012a). I suggest that during young adulthood Tibanica peoples, especially males, were consuming lots of maize in their diets, both as food and drink. As people aged, their dental health became compromised due to the nature of consuming a diet with high proportions of maize, causing dental infections and tooth loss with increasing age. During middle and older age people may have consumed less maize in daily meals due to these dental issues but may have maintained their consumption of maize beer (*chicha*) with age, since imbibing drinks doesn't require teeth. This change in diet but maintenance of another form of maize consumption (*chicha*) is one possible explanation for the decline in $\delta^{13}C$ data with age while allowing for the continuation of relatively enriched carbon

dietary chemistry across the entire lifetime. Older individuals who often have lost most of their teeth (Miller, personal observation of Tibanica skeletal collection) may have supplemented their meals with more C_3 foods, perhaps tubers, which are softer, less gritty and may not require a full mouth of healthy teeth to masticate.

Table 3.3: Summary data for each tissue type and each isotope measured, grouped by sex and age categories.

Tissue Type and Isotope Measured	FEMALES				MALES			
	n	mean	SD	SE mean	n	mean	SD	SE mean
Bone Collagen - Carbon								
Young (18-29)	17	-11.8	0.7	0.2	12	-11	1.2	0.3
Middle (30-49)	37	-12.6	0.9	0.1	53	-11.4	1	0.1
Older (50+)	14	-13.2	1.3	0.3	17	-12.2	1	0.2
Bone Collagen - Nitrogen								
Young (18-29)	17	9.2	0.6	0.1	12	9.4	0.8	0.2
Middle (30-49)	37	9.4	0.5	0.1	53	9.8	0.4	0.1
Older (50+)	14	9.3	0.5	0.1	17	9.7	0.6	0.1
Bone Apatite - Carbon								
Young (18-29)	14	-6.3	0.7	0.2	12	-6	0.8	0.2
Middle (30-49)	21	-7.1	0.7	0.2	50	-6.3	0.7	0.1
Older (50+)	10	-7.2	1.2	0.4	15	-6.6	0.9	0.2
Tooth Enamel - Carbon								
Young (18-29)	15	-4.2	1.6	0.4	10	-3.9	1.2	0.4
Middle (30-49)	34	-4.7	1	0.2	63	-4.1	1.3	0.2
Older (50+)	9	-5.1	1.5	0.5	15	-4	1.2	0.3
Tooth Dentin - Carbon								
Young (18-29)	15	-11.9	1.4	0.4	10	-11.5	1.4	0.4
Middle (30-49)	35	-12.2	1.1	0.2	64	-11.3	1.3	0.2
Older (50+)	10	-12.2	1.5	0.5	16	-11.3	1.5	0.4
Tooth Dentin - Nitrogen								
Young (18-29)	15	10.2	0.7	0.2	10	10	0.8	0.3
Middle (30-49)	35	10.4	0.7	0.1	64	10.2	0.6	0.1
Older (50+)	10	10.4	0.6	0.2	16	10.4	0.5	0.1
Bone Apatite - Oxygen								
Young (18-29)	14	-7.9	0.7	0.2	12	-8.1	0.8	0.2
Middle (30-49)	21	-7.9	1	0.2	50	-8.1	1	0.1
Older (50+)	10	-8.2	0.7	0.2	15	-7.9	2.4	0.6
Tooth Enamel - Oxygen								
Young (18-29)	15	-7.7	1	0.3	10	-8	1	0.3
Middle (30-49)	34	-7.5	1	0.2	63	-7.6	0.7	0.1
Older (50+)	9	-7.9	1.1	0.4	15	-7.9	0.8	0.2

Childhood diet

Childhood diet was assessed through studying dental tissues (enamel and dentin) for carbon and nitrogen isotopes. Analysis of second and third molars provides dietary data from the period of childhood corresponding approximately to ages 5 through 15. I found no statistically significant differences between dietary data recorded in the second molar samples from the third molar samples (for any isotope measured), indicating that dietary data is relatively stable across that period of childhood/adolescence and therefore allows us to combine the data from those teeth to study childhood dietary practices. 134 individuals have second molar data and 42 have third molar data (total sample n = 176; females = 60, males = 90, ambiguous/indeterminate = 26; Appendix C).

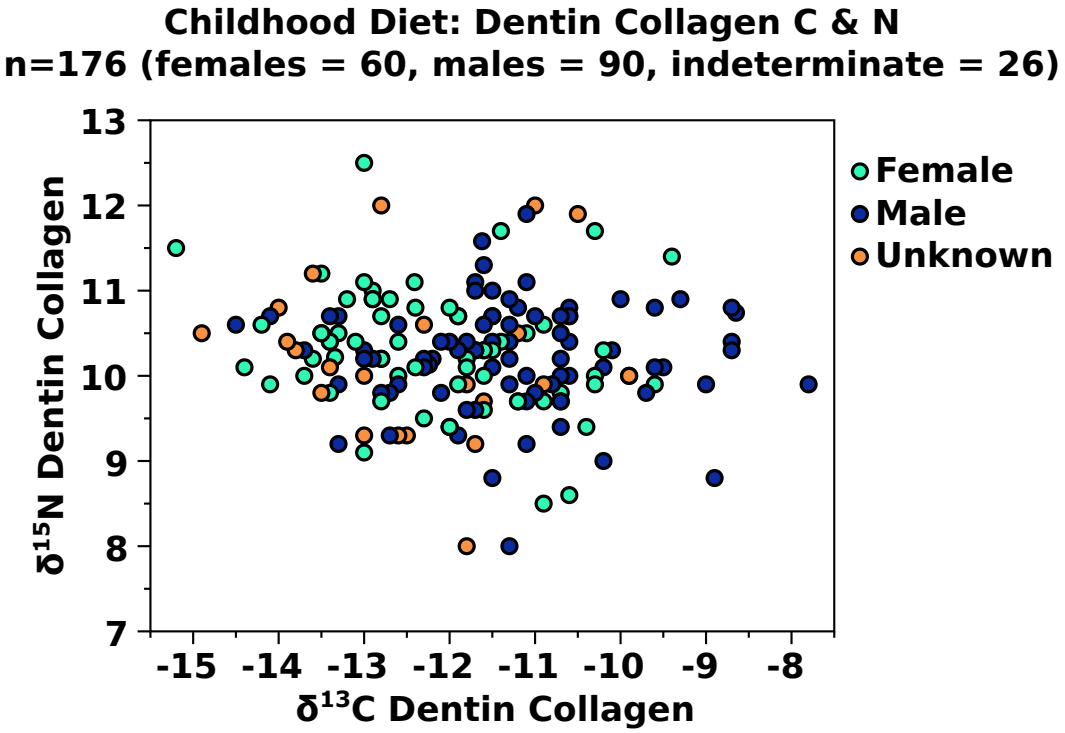

Figure 3.14: Tooth dentin collagen $\delta^{13}C$ and $\delta^{15}N$ data (skewed towards protein portions of diet). Second and third molar samples represent childhood diet covering ages 5-15 years. Sex is known as the teeth were extracted from adult individuals: green circles are females, dark blue circles are males, and orange circles are of ambiguous or indeterminate sex. Note the large range for both C and N isotopes. During childhood, males consumed more C_4-type foods than females, setting the stage for life-long dietary differences between the sexes.

Overall, the diets from childhood are very similar to adulthood diets which is not especially surprising as we would expect children to be eating many of the same foods as adults, being fed by family and kin during mealtimes (Table 3.3; Figures 3.14 and 3.15). There may have been some foods that were not considered 'appropriate' foods for children, as is observed in many cultures, but we currently have no way of identifying any specific food(s) that might have been taboo or especially good for Muisca children. Interestingly, the range for every isotope measured (carbon from enamel and dentin, and

nitrogen from dentin) is wider during childhood, while adulthood dietary range is slightly more restricted. For example, for childhood diet enamel $\delta^{13}C$ ranges from -7.9 to -1.2‰ (a span 6.7‰), while bone apatite $\delta^{13}C$ reflecting adulthood diet ranges from -9.5 to -4.1‰ (a span of 5.4‰). Dentin $\delta^{13}C$ (childhood) ranges from -15.2 to -7.8‰ (covering 7.4‰), while bone collagen $\delta^{13}C$ ranges 7‰, from -15.1 to -8.1‰. Similarly, dentin $\delta^{15}N$ ranges from 8.0 to 12.5‰ (spanning 4.5‰) while adult bone collagen $\delta^{15}N$ ranges from 7.7 to 11.1‰ (3.4‰ span).

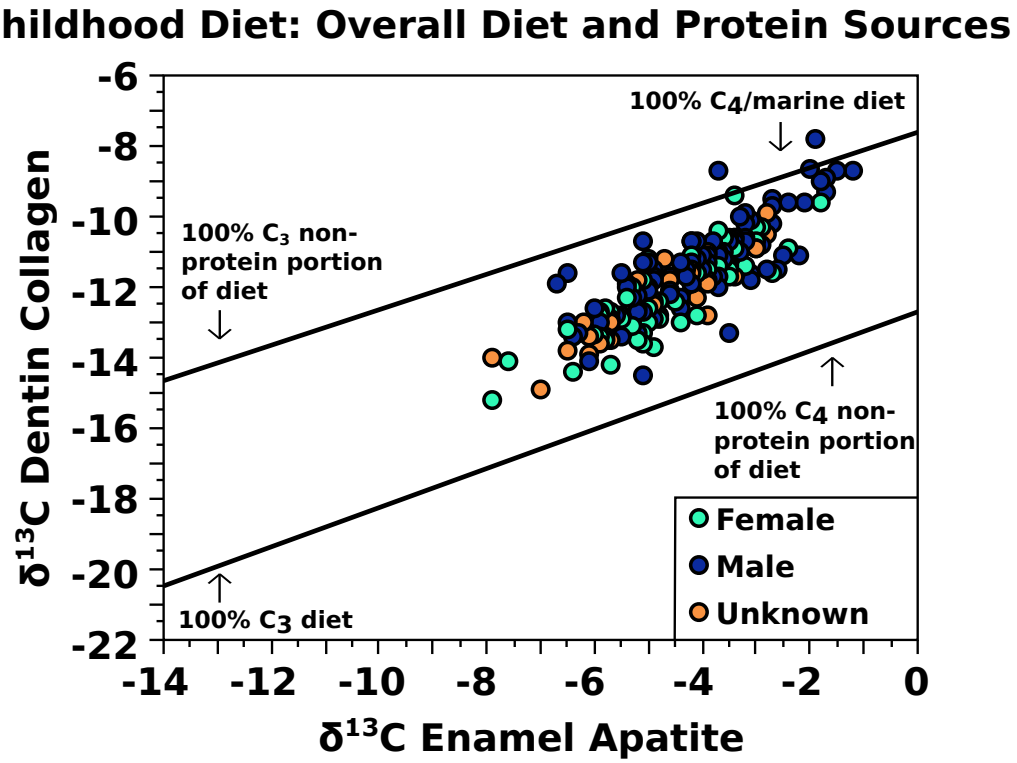

Figure 3.15: Tooth enamel $\delta^{13}C$ and tooth dentin collagen $\delta^{13}C$ for Tibanica childhood diet (comparing total dietary carbon to carbon from protein sources). Sex is known as the teeth were extracted from adult individuals: green circles are females, dark blue circles are males, and orange circles are of ambiguous or indeterminate sex. Data are plotted with regression lines from Froehle et al., (2010) to indicate dietary composition (arrows point to: 100% C4/marine diet; 100% C4 non-protein portion of diet; 100% C3 non-protein portion of diet; 100% C3 diet). $\delta^{13}C$ bone apatite is approximately 10‰ more positive than $\delta^{13}C$ diet and $\delta^{13}C$ bone collagen is approximately 5‰ more positive than $\delta^{13}C$ diet. Note that male children are closer to the C_4/marine protein line during childhood compared to female children and are also shifted farther to the right on the x-axis, indicating dietary differences between the sexes were practiced from childhood as part of gendering children into particular social identities.

Is it possible that children are eating diets that are more varied than adult diets? What we may be seeing is actually a reduction in dietary variation during childhood. One possible explanation for the larger isotopic ranges observed in childhood dietary data may be a reflection of children's eating habits. It is common to see children prefer certain

foods over others and then eat those repeatedly, to the exclusion of other foods. This would have an effect on the isotopic signature recorded in teeth, as the chemistry would be reflective of a more restricted diet, with fewer foods contributing their chemical elements thereby dominating the composition of the subsequent tissue that is formed from those ingredients. In this way, the larger range in children's diets may be reflecting how features of childhood diet (taste experiences which reinforce food behaviors) are more restricted during this period of life, and that as these individuals aged into adulthood their diets in effect became more similar as they ate more foods across different food groups. This is a hypothesis that can be tested in other populations to see if similar patterns exist and to better understand the biological and cultural aspects of children's food practices.

With the interest in understanding the potential effects of dietary privilege related to status, I tested to see if those individuals buried with grave goods in adulthood had any differences in their childhood diets compared to childhood diet for those burials without grave goods. I found no significant differences between the groups for any isotope measured. Therefore, individuals who were considered higher status at death (as evidenced by burial with durable grave goods) did not show any dietary differences in youth compared to their peers (no dietary privilege during childhood).

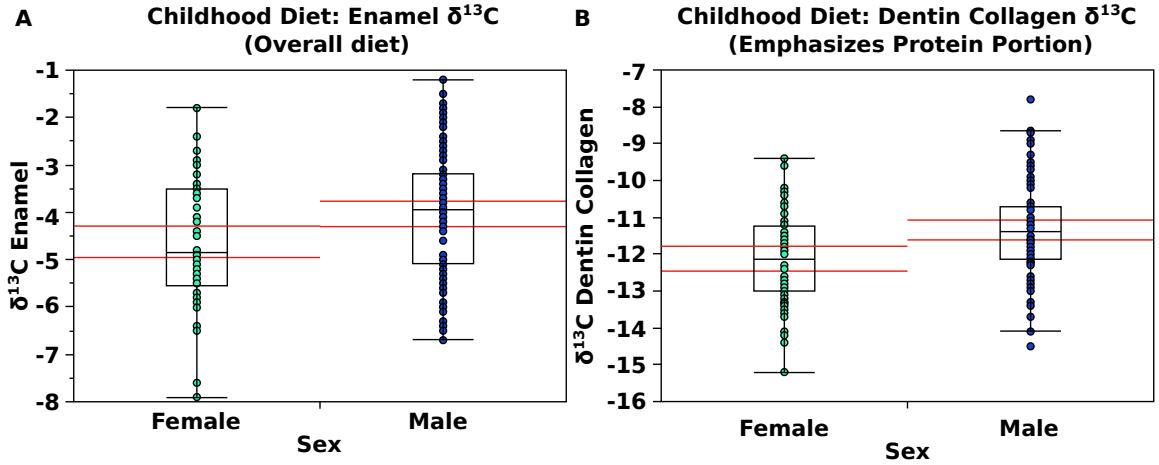

Figure 3.16a: Tooth enamel $\delta^{13}C$ data (total dietary carbon from childhood diet) plotted by sex. Females are on the left as green circles; males are on the right as dark blue circles. The red lines are the 95% confidence interval of the mean.

Figure 3.16b: Tooth dentin collagen $\delta^{13}C$ data (skewed towards dietary protein sources consumed during childhood) plotted by sex. Females are represented by green circles and males are dark blue circles. The red lines are the 95% confidence interval of the mean.

As can be seen in both figures - during childhood, male diets have significantly more positive $\delta^{13}C$ values than females for both $\delta^{13}C$ data sets, suggesting that privileged access to C_4-type foods began at a young age for Tibanica males.

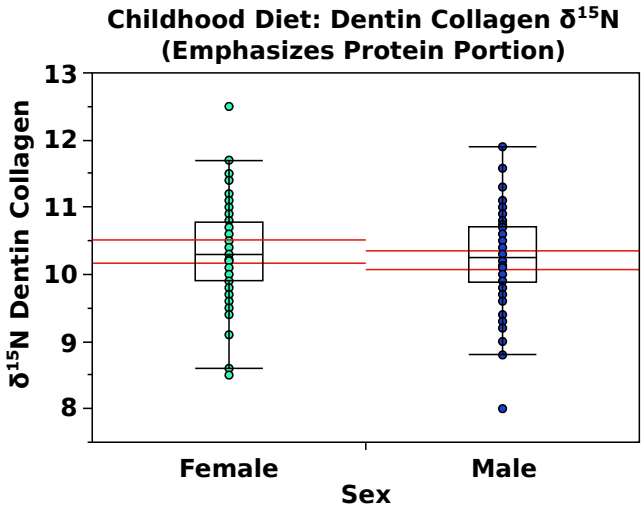

Figure 3.17: Tooth dentin collagen $\delta^{15}N$ (emphasizes protein sources consumed during childhood) plotted by sex. Female data is plotted as green circles and male data is plotted as dark blue circles. The red lines are the 95% confidence interval of the mean. Note that during childhood male and female children have very similar $\delta^{15}N$ data, indicating that protein consumption (amount and type) was similar between the sexes at this age.

There are significant dietary differences between the sexes during childhood. For both enamel and dentin collagen $\delta^{13}C$ we observe statistically and meaningfully significant differences between female and male childhood diets (Figure 3.16a,b). For male children the mean $\delta^{13}C_{enamel}$ = -4.0‰ while the female $\delta^{13}C_{enamel}$ average = -4.6‰ (Wilcoxon p-value = 0.0146). For the dentin collagen, the female $\delta^{13}C$ mean = -12.1‰, and the male mean $\delta^{13}C_{dentin\ collagen}$ = -11.3‰ (Wilcoxon p-value = 0.0008). These carbon isotope differences indicate that even as children, males were given greater amounts of C_4-type foods (likely maize) than their female peers. Based on the teeth sampled we can see that dietary differences were already occurring for children as young as five years old, suggesting that maize is a food that is introduced early to the diet, with an even greater amount given to boys (possibly in the form of *chicha*). Interestingly, there is no statistically significant difference in $\delta^{15}N_{dentin\ collagen}$ values between males and females during childhood (female $\delta^{15}N$ mean = 10.3‰, male $\delta^{15}N$ mean = 10.2‰; Figure 3.17). Therefore, children had access to similar amounts of protein and from similar trophic levels, regardless of their sex, but different amounts of maize.

Conclusions

The isotopic data presented here demonstrates that dietary practices for the Tibanica people were intertwined with a person's sex and age. By studying multiple tissue types and incorporating different isotopes we can see how many dietary habits are formed during childhood and some of these are maintained while others change over the life-course. Particular foods such as maize (as a food and/or as a beverage), and potentially certain animal foods (such as birds or fish) are consumed in greater proportions by males within this Muisca community. Already by age 5 we see male children have a greater proportion of maize in their diets than their female peers (sisters/cousins/friends) of the same ages. This higher level of maize consumption

continues for males over their entire lifetime until death, with only a slight decline in old age, ironically possibly related to dental disease associated with maize consumption. Females do not see changes in maize consumption between childhood and adulthood, but do have a slight decline in maize consumption as they age during adulthood, which we hypothesize is related to dental problems limiting their consumption of maize as a food, but not as a drink (as teeth are not required).

Dietary protein consumption suggests a complex interaction of both sex and age – during childhood all children had similar dietary protein patterns but in adulthood male and female diets diverge slightly for their protein components. As boys become men they eat an increasing proportion of C_4-type foods: possibly more *chicha* and/or more meat from birds and fish. The fact that this differentiation is visible in the adulthood data but not in the childhood data suggests that another dietary process (meat eating and/or *chicha* drinking) that is tied to social identity (masculinity) emerges after adolescence, potentially indicating that these foods are also tied to particular sex and age statuses within the Tibanica community. Other Andean communities have documented the increased consumption of *chicha* by males, despite the fact that women are most often the *chicha* brewers (Morris, 1979; Hastorf, 1991; Somerville et al., 2015). Males may have had more access to local freshwater fish, possibly being the ones who participated in fishing activities or related to trading activities. Rojas de Perdomo (1994) notes that the Muisca language has a number of words to describe fish and tools associated with fishing (in the Chibchan language), suggesting a linguistic line of evidence that fish were a regular food item for Muisca peoples. Muisca sites are often located near rivers, lakes, and other freshwater sources, and weights for fish nets have been recovered from Muisca archaeological sites (Broadbent, 1974; Boada Rivas, 2007; Aristizabal, personal communication). If fishing was a male task, then they may have had greater access to this specific food while on fishing trips. Additionally, the Muisca would extract salt from local earthen sources and trade it with neighboring groups, who would then use it to produce salt-cured fish, something the Muisca might have traded for (Rojas de Perdomo, 1994). If men were travelling on trading expeditions more often than women, then they may have had greater access to these salt-cured fish on a regular basis, as trading markets were regular events for the Muisca (Langebaek Rueda, 1987). Some Andean freshwater fish have been documented as having high carbon values (Miller et al., 2010). At present, we do not have any archaeological fish samples to analyze for isotopic data at this time, so this must remain a hypothesis.

The incorporation of greater amounts of maize and certain proteins for males, and the consumption of maize with a slightly greater reliance on C_3 type foods for females, were regular practices that intertwined the social and biological experiences of being a gendered person within this Muisca community. The changes that are observed over different age categories also indicate the social timing aspects of how gendering is an on-going way of being that encompasses numerous practices (such as diet and labor), and these gendered identities (and associated praxes) may change as we age. The evidence for the early incorporation of significant amounts of maize into the diet of boys can be viewed as one of the practices that may have been part of the social processes of identity construction and maintenance. Indeed eating and drinking maize are an important part of what it means to make and be a boy in this community (i.e. “boying the boy” through food, see Joyce, 2000). Young girls were also part of these embodied dietary processes of

gendering, by consuming diets that had different compositions than their brothers/cousins/friends.

Food practices are daily activities where social identities are formed and maintained, creating and reinforcing lines of division within and across the biosocial experiences of sex and age. These differences in access reveal deeper parts of the social fabric that structure daily life for the Tibanica peoples. Individuals are socialized into particular identities and roles through food practices that at times unite and at times divide them. Taken together, these food practices can be viewed as a reflection of how what it means to be a Muisca woman or man is entangled in the larger network of social, political, economic, and ideological relations that the person lived in. Being a Muisca person means eating certain Muisca foods: being an old man or a young girl are experiences that are inextricable from the social networks that create and reinforce those identities, and diet is one aspect of these embodied expressions.

Chapter 4: Sex- and Age-Related Patterns in Physical Activity: Cross-sectional geometry data from femurs and humerii

Introduction

Understandings of ancient peoples' daily activity patterns remain elusive in the archaeological record for most cultures across time and space. Bioarchaeological research has attempted to study physical activity, movement, repeated stress, and consequential changes to skeletal health through investigations of bone structure and shape (Ruff and Hayes, 1982; Bridges, 1989; Stock et al., 2011; Ruff and Larsen, 2014). Here we present new data examining femoral and humeral cross-sectional geometric (CSG) measurements assessing bone quantity, robusticity and strength, from a pre-Columbian Muisca population (AD 1000-1400) from the Northern Andes of Colombia in order to investigate physical activity differences between males and females, and across three broad, adult age groups. While cross-sectional geometry studies have been gaining traction within the bioarchaeological and paleoanthropological communities (particularly as lower cost, non-invasive methods become more available), very few studies have been published that examine populations from South America (but see Pomeroy, 2013). Therefore, this research also provides new data for comparing populations within this area of the Americas.

Bone is a complex, adaptive tissue that is constantly changing over the lifetime through modeling and remodeling processes (Frost, 1987, 1990, 2003; Parfitt, 2003; Raisz, 2004; Hall, 2005). The development and maintenance of the human skeleton is influenced by internal and external stimuli such as genetic information, nutrition, hormones, and physical activity or lack thereof (Garn, 1970; Sowers, 1996; Nelson et al., 2002; Rosen, 2002; Nelson and Villa, 2003). The skeletal system, and long bones in particular, can be viewed within a biomechanical framework where aspects of skeletal morphology are directly related to the forces that are exerted on bone and the ways in which bone responds accordingly (Ruff, 2008). Often referred to as "Wolff's Law," the central idea underpinning bone biomechanics reflects the functional adaptation of bone (Pearson and Lieberman, 2004; Ruff et al., 2006). Bone morphology and structure are understood to be a product of the ways any particular skeletal element has been used (through repeated mechanical loadings) to influence its development and maintenance over the life of the organism. For example, strenuous activity and exercise exert force on muscles and bones causing a feedback system where the body responds by increasing muscle mass and altering the underlying bone structure to support those forces, while decreased activity and strain can lead to significant bone resorption and loss (Krølner and Toft, 1983; Schneider et al., 1995; Ruff et al., 2006; LeBlanc et al., 2007; Ruff, 2008). Repetitive or extreme mechanical loading is thought to be one of the most critical reasons that bone remodels (Cullinane and Einhorn, 2002; Martin, 2003; Burr, 2004; Ruff et al., 2006). Since bone morphology relates to the habitual activities of an individual, bioarchaeologists can study skeletal data in order to reveal long-term behavioral patterns of ancient populations (Ruff and Larsen, 2014).

Mechanical loading stimulates bone modeling and remodeling, and as a result the cross-sectional properties of a long bone reflect adaptation to habitual mechanical loads. Mechanical strains on the diaphysis of a long bone cause it to respond and change in

shape in quantifiable ways that can be understood in similar ways that engineers conceptualize beams in any construction, therefore the principle of "beam theory" has been applied to skeletal elements (Huiskes, 1982; Ruff, 2005). Forces act on the beam/bone and these loadings can be measured about various axes to understand the threshold of the structure before fracture (Ruff, 2008). Cross-sectional geometric measurements including quantification of total bone area (subperiosteal area), cortical area, medullary area, and shape measurements including indicators of rigidity and strength are used to examine inter- and intra-population differences in activity patterns (Ruff and Hayes, 1983a; b; Ruff et al., 1984; Stock and Pfeiffer, 2004; Pomeroy, 2013).

Forces of compression, tension, bending and torsion all interact on a bone's structure spurring changes to its shape and form, and these properties can be measured using cross-sectional geometric data. The standard properties that are measured are listed in Table 4.1. Cortical area (the quantity of bone in cross-section) is related to axial rigidity and strength (Ruff, 1999). Total area, cortical area and medullary area (TA, CA and MA, respectively) are also important measurements as they provide information about changes to the external (periosteal) and internal (endosteal) bone surfaces and have consequential effects on other CSG measurements (Ruff and Hayes, 1983b, 1988; Ruff, 1999). Second moments of area (SMAs) reflect bending (I) rigidity in relation to an axis and in bone are typically measured relative to the anatomical planes of anteroposterior (Ix) and mediolateral (Iy) (Ruff, 1999, 2008). The maximum bending rigidity (Imax) and minimum bending rigidity (Imin) are measured perpendicular to each other in cross-section (Ruff and Hayes, 1983b). J is the polar second moment of area reflecting torsional rigidity and average bending rigidity because it is the result of the sum of I_{max} and I_{min}, and "J provides the most accurate estimate of average bending rigidity" (Lieberman et al., 2004:169; Also see Ruff, 2008).

These CSG measurements have been used to address a variety of questions ranging from the study of early hominids and modern humans (Trinkaus, 1976; Ruff et al., 1993; Trinkaus and Churchill, 1999; Trinkaus and Ruff, 1999; Shaw and Stock, 2013) to the labor changes that accompany shifts in economic or subsistence practices (Ruff and Hayes, 1983a; b; Ruff et al., 1984; Bridges, 1989; Stock and Pfeiffer, 2004; Wescott and Cunningham, 2006; Sparacello and Marchi, 2008; Ogilvie and Hilton, 2011; Sparacello et al., 2011; Stock et al., 2011). New methods, such as computed tomography (CT), allow for non-destructive analysis by capturing a cross-sectional image of the long bone that can then be measured and analyzed using computer software (Ruff, 2008).

Table 4.1 Cross-sectional geometry measurements and their definitions (following Ruff, 2008)

Cross-Sectional Measurement	Definition
Total Subperiosteal Area (**TA**)	entire area measurement within subperiosteal surface (mm2)
Cortical Area (**CA**)	area measurement related to tensive/compressive strength (mm2)
Medullary Area (**MA**)	area measurement of medullary cavity (mm2)
Percent Cortical Area **(%CA**)	percent calculated by: (CA/TA) x 100
Second Moment of Area antero-posterior axis (**Iy**)	medio-lateral (M-L) bending rigidity (mm4)
Second Moment of Area medio-lateral axis (**Ix**)	antero-posterior (A-P) bending rigidity (mm4)
Minimum Second Moment of Area (**Imin**)	minimum bending rigidity (mm4)
Maximum Second Moment of Area (**Imax**)	maximum bending rigidity (mm4)
Polar Second Moment of Area (**J**)	torsional and (twice) average bending rigidity (mm4)

Archaeological studies have utilized CSG analysis to investigate questions of how physical labor practices correspond to particular groups. Although studies of prehistoric South American skeletal samples are limited, Pomeroy (2013) compares femoral and tibial samples from prehistoric samples from the oasis of San Pedro de Atacama. Pomeroy (2013) found statistically significant differences in CSG variables that correlated to changes in mobility associated with long-distance travel. The Middle Horizon (MH, AD 500-1000) peoples had the lowest levels of robusticity (and therefore mobility) in comparison to the people who lived during the transitional period between the MH-LIP (Late Intermediate Period, AD 1000-1450) who show the highest measures on TA, Ix/Iy, and J for the femur and the tibia. Those MH-LIP peoples (both men and women) were interpreted as having increased activity related to long-distance travel, possibly trading activities, as this area of the Atacama Desert was likely an important hub on caravan/trading routes (Pomeroy, 2013). Recent work by Maggiano and collaborators (2008) found patterns of labor changed through time for Maya from Xcambó, in particular the activities of males became less-strenuous on the upper body as indicated by a decrease in humeral robusticity. Additionally, Mayan Xcambó women showed femoral and humeral indicators of similar workloads despite some women being from the elite group, therefore suggesting a strong sexual division of labor that united women's work despite status differences (Maggiano et al., 2008).

Studying the morphology of femurs and humerii of individuals from Tibanica provides an opportunity to investigate the different labor patterns that existed within this society, particularly along the lines of sex and/or age group. This study compares female and male individuals within the same Muisca population to examine levels of sexual dimorphism in femoral and humeral cross-sectional properties and see if these are linked to gendered activity patterns. It was predicted that the males would show greater measures of robusticity for both femurs and humerii than females due to greater mobility and higher levels of strenuous activity. Additionally, age-related changes to the femur were predicted for both males and females, with the older age category showing

decreased A-P loading (lower Ix/Iy and Imax/Imin) than the young and middle aged groups (within the same sex), related to decreased mobility in older age. We also hypothesize that both males and females would show bilateral asymmetry reflecting specialization in tasks and hand dominance (usually right-hand dominance), features of the upper arms that are commonly observed in many populations. This cross-sectional geometry study will provide new information about the interactions of sex and age on physical activity patterns for Muisca people, a topic that has not been previously considered using bioarchaeological data.

Materials and Methods

The Tibanica sample I focused my study on is composed of 63 adult individuals (32 females, 31 males) which were analyzed for femoral CSG data. Individuals with complete, fully-fused femurs were selected for analysis but preservation bias did not allow for standardization of side (therefore most samples are left femurs, but 19 are right femurs). Thirteen individuals had both left and right femurs analyzed to compare CSG variables between sides of the body. No statistically significant differences were found between left and right measures for raw TA, CA, Ix, Iy, Imax, Imin, and J data. Therefore, both left and right femurs are used in this study. A sub-set of these same individuals (n=33; 16 females, 17 males) had both humerii (left and right) intact, and were included in humeral CSG analyses. Sex and age-at-death was determined by examination of the skull and pelvis, including assessment of the pubic symphysis and auricular surfaces (Lovejoy, 1985; Lovejoy et al., 1985; Brooks and Suchey, 1990; Buikstra and Ubelaker, 1994). Individuals were then grouped into three broad age categories: young (ages 18-29 years), middle (ages 30-49 years), and older (aged 50+ years).

Computed tomography (CT) images were taken at an IDIME medical diagnostic center in Bogotá, Colombia, using a Toshiba One Aquilion machine that was set to 0.5mm scan slices over a 1.5 mm area. The scan time was 0.5 seconds at 120kV / 175mAS. Resulting images were used to calculate cross-sectional data using ImageJ (NIH YEAR) and MomentMacro (Ruff, 2008; Ruff et al., 2015). Femur bones were scanned at the midshaft (50% section) and humerii were scanned at the mid-distal, 35% of the length from the distal epiphysis (following Ruff and Hayes, 1983a; Stock et al., 2011). Measurements were taken using sliding digital calipers before CT scanning to ensure accurate imaging location, and to calculate stature and body mass estimates. On all individuals that were CT scanned the following measurements were taken when possible: femur maximum length, femur bicondylar length, femur length', femoral head diameter, humerus maximum length, humerus bicondylar length, humeral head diameter, bi-iliac breadth (Ruff and Hayes, 1983a; b; Trinkaus et al., 1994; Ruff, 2002b, p 20; Auerbach and Ruff, 2004; Pomeroy and Stock, 2012).

Body size must be accounted for when comparing data within and between samples (Ruff et al., 1993; Ruff, 2000a; b). Stature was estimated for the Tibanica sample using sex-specific calculations from Pomeroy and Stock (2012). The equations used were:

Female height in cm = 49.147 + (Bicondylar Femur Length in cm X 2.6)

Male height in cm = 47.207 + (Bicondylar Femur Length in cm X 2.705)

Body mass was estimated by using the average resulting from three published equations that use femoral head diameter (Ruff et al., 1991 (with the 10% adjustment for adiposity; McHenry, 1992; Grine et al., 1995). A small number of individuals (n=25) had good pelvis preservation and therefore were also assessed for body mass using bi-iliac breadth measurements (Ruff et al., 2005). Calculations comparing these morphometric vs mechanical body mass measurements show good concordance between these two mass estimations for this sample (R-squared = 0.72), assuring us that the body mass correction using femoral head data is a robust correction to apply to this CSG data (Ruff, 2002a; Auerbach and Ruff, 2004; Ruff et al., 2005; Pomeroy and Stock, 2012).

Most cross-sectional geometry measurements need to be corrected for body mass differences that occur within any population and could skew results and interpretations, particularly between the sexes if there is significant dimorphism. This study uses a standardized method that combines body mass estimates and bone length measurements in formulae (see Ruff and Larsen, 2014). In these calculations, total area (TA), cortical area (CA), and medullary area (MA) are standardized by dividing by body mass estimate times 100 (Ruff, 2008). Second moment of area measures (Ix, Iy, Imax, Imin, J) are standardized by body mass times bone length^2 (then multiplied by 10^5; see Stock and Shaw, 2007; Ruff and Larsen, 2014). Measurements expressed as a percent or other ratio (%CA, Ix/Iy, Imax/Imin) do not need additional standardization. Bilateral asymmetry was assessed in humeral measurements through both directional asymmetry (%DA) and absolute asymmetry (%AA) calculations (Auerbach and Ruff, 2006; Pomeroy and Zakrzewski, 2009):

%DA = ((right – left)/(mean of left and right))X100

%AA = ((maximum – minimum)/(mean of maximum and minimum))X100

Absolute asymmetry (%AA) shows the total asymmetry while directional asymmetry (%DA) indicates the direction and degree of asymmetry (negative values indicate left side is larger while positive values mean right side is larger). Percent sexual dimorphism was also calculated (Maggiano et al., 2008):

%dimorphism = [(male mean – female mean)/female mean]X100

Statistical testing was completed using the software package JMP Pro 11. To test for differences between groups (such as age or sex) independent t-tests and Tukey-Kramer Honestly Significant Difference (Tukey-Kramer HSD) tests were applied when the data showed a normal distribution and in cases where non-normal distributions were noted other tests such as a Wilcoxon/Kruskal-Wallis (W/K-W) test were used (the W/K-W was also run on all samples due to small sample sizes and only in a few notable cases below were results different between these tests). Two-way ANOVA tests were also completed to look for interaction effects between age and sex on all variables.

Results

The Tibanica sample shows significant sexual dimorphism (Figure 4.1), and cross-sectional geometry results suggest a gendered division of labor with some age-related changes as well. Overall, Tibanica adult males are significantly taller than females (t-test p-value of <0.0001). The mean adult female height is 148.5 cm (SD=5.9cm) and the mean adult male height is 161.1 cm (SD=5.6cm). One female was very petite (her stature is estimated at 130.01cm, over 3 standard deviations from the female mean) but she appeared non-pathological and therefore was included in all subsequent analyses (this female is only an "outlier" for her stature but not for any other cross-sectional variables when her small size is accounted for in the body size corrections). A study of a larger portion of the Tibanica population also found significant differences in stature for males and females in this population (Langebaek et al., In Press).

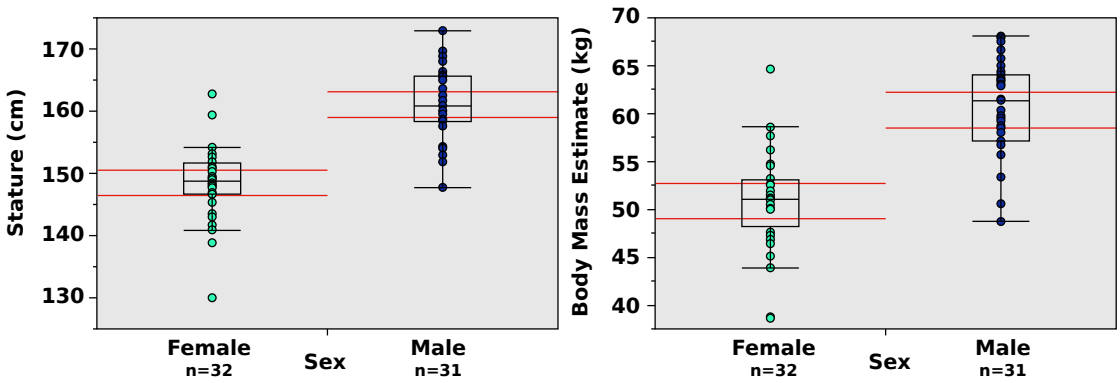

Figure 4.1: Stature and body mass estimates (left and right, respectively) for Tibanica males (dark blue circles) and females (green circles). Stature measures were estimated using the equations from Pomeroy & Stock, 2011. Body mass was estimated from the average of three estimates using equations from McHenry 1992; Grine et al., 1995; Ruff et al., 1991 with a 10% adjustment for adiposity. The red lines are the 95% confidence interval of the mean.

Femur

For the Tibanica sample in general (n=63, females = 32, males = 31) the percent sexual dimorphism in the femur is low to moderate across all cross-sectional properties, with males and females showing some dimorphism (1-12% depending on property, see Table 4.2), with the highest difference found in the rigidity measures (Ix, Iy, Imax, Imin, J), though not as extreme as has been observed in other populations (see discussion below). Males have statistically larger femoral TA (t-test p-value 0.0056) and CA (t-test p-value 0.0111) than females (Figure 4.2).

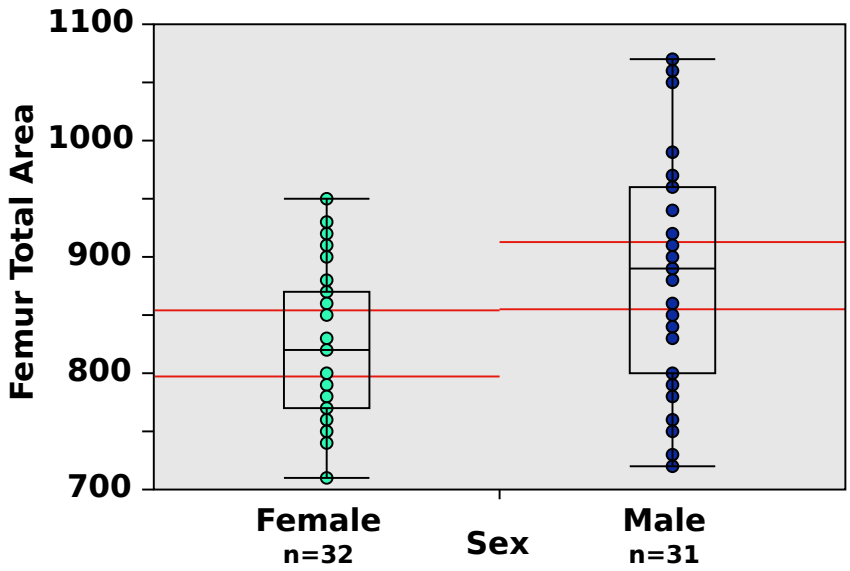

Figure 4.2: Femur total area (TA) measurements for Tibanica females (green circles) and males (blue circles). Area measurements are standardized to correct for body size differences (divided by body mass estimate x 100). The red lines are the 95% confidence interval of the mean.

Table 4.2: Tibanica stature estimations and femoral cross-sectional area measurements (total area, TA; cortical area, CA; percent cortical area, %CA; medullary area, MA) grouped by sex and age categories. Numbers in bold are statistically different.

	FEMALES			MALES			
	n	Mean	SD	n	Mean	SD	% Sexual Dimorphism
Stature Estimation	32	**148.5**	5.9	31	**161.1**	5.6	8.5
Total Area (TA)							
Combined Age Groups	32	**825.6**	64.2	31	**883.9**	94.3	7.1
Young (18 - 29 years)	10	811.9	78.0	7	**828.8**	71.2	
Middle (30 - 49 years)	14	831.3	54.1	15	877.3	95.3	
Older (50+ years)	8	835.4	66.8	9	**938.6**	86.4	
Cortical Area (CA)							
Combined Age Groups	32	**616.4**	65.6	31	**664.6**	79.7	7.8
Young (18 - 29 years)	10	623.9	70.0	7	649.0	66.1	
Middle (30 - 49 years)	14	623.1	51.1	15	660.0	88.5	
Older (50+ years)	8	595.4	85.2	9	684.4	78.5	
Percent Cortical Area (% CA)							
Combined Age Groups	32	74.6	5.7	31	75.3	6.5	0.9
Young (18 - 29 years)	10	76.8	3.2	7	78.3	4.6	
Middle (30 - 49 years)	14	75.1	5.7	15	75.3	6.8	
Older (50+ years)	8	71.2	6.8	9	73.1	7.1	
Medullary Area (MA)							
Combined Age Groups	32	209.8	49.9	31	219.6	67.4	4.6
Young (18 - 29 years)	10	187.9	27.6	7	179.9	41.7	
Middle (30 - 49 years)	14	208.2	52.6	15	217.4	64.5	
Older (50+ years)	8	240.0	56.6	9	254.2	75.6	

Table 4.3: Tibanica femur second moment of area measurements (Ix, Iy, Ix/Iy, Imax, Imin, Imax/Imin, J) grouped by sex and age categories. Numbers in bold are statistically different.

	FEMALES			MALES			
	n	Mean	SD	n	Mean	SD	% Sexual Dimorphism
Ix							
Combined Age Groups	32	**182.0**	32.0	31	**202.3**	38.9	11.2
Young (18 - 29 years)	10	189.3	39.8	7	**171.5**	17.7	
Middle (30 - 49 years)	14	174.7	23.6	15	201.9	34.5	
Older (50+ years)	8	185.6	35.5	9	**226.8**	43.1	
Iy							
Combined Age Groups	32	**174.4**	30.8	31	**195.8**	43.1	12.3
Young (18 - 29 years)	10	157.7	38.1	7	172.6	26.6	
Middle (30 - 49 years)	14	179.2	25.4	15	191.3	35.1	
Older (50+ years)	8	186.9	22.2	9	221.5	55.2	
Ix/Iy							
Combined Age Groups	32	1.1	0.2	31	1.0	0.2	-1.0
Young (18 - 29 years)	10	**1.2**	0.2	7	1.0	0.1	
Middle (30 - 49 years)	14	**1.0**	0.1	15	1.1	0.2	
Older (50+ years)	8	**1.0**	0.1	9	1.0	0.2	
Imax							
Combined Age Groups	32	**197.0**	32.3	31	**219.8**	40.2	11.6
Young (18 - 29 years)	10	197.6	40.1	7	**189.5**	22.6	
Middle (30 - 49 years)	14	193.3	7.3	15	215.7	31.6	
Older (50+ years)	8	202.8	33.2	9	**250.0**	45.5	
Imin							
Combined Age Groups	32	**159.3**	26.5	31	**178.3**	38.7	11.9
Young (18 - 29 years)	10	149.3	35.4	7	**154.6**	19.8	
Middle (30 - 49 years)	14	160.6	20.4	15	177.4	35.0	
Older (50+ years)	8	169.7	21.4	9	**198.3**	47.4	
Imax/Imin							
Combined Age Groups	32	1.2	0.1	31	1.3	0.0	0.8
Young (18 - 29 years)	10	**1.3**	0.1	7	1.2	0.1	
Middle (30 - 49 years)	14	**1.2**	0.1	15	1.2	0.1	
Older (50+ years)	8	**1.2**	0.1	9	1.3	0.1	
J							
Combined Age Groups	32	**356.3**	56.5	31	**398.1**	76.3	11.7
Young (18 - 29 years)	10	346.9	75.2	7	**344.1**	40.3	
Middle (30 - 49 years)	14	353.9	43.8	15	393.2	63.6	
Older (50+ years)	8	372.5	53.7	9	**448.3**	89.9	

For Ix (A-P bending rigidity) there is both a statistically significant difference between the sexes, and within the males across age groups (Figure 4.3; Table 4.3). There is a statistically significant age-related increase in femoral Ix with younger males having a lower Ix value than older males (Wilcoxon rank sum test p-value = 0.0175; pair comparison Young-Mid p-value is 0.0483; pair comparison Young-Older p-value is 0.0111). The females do not show an age-related change in femoral Ix. For Iy (femur, M-L bending rigidity) there is a statistically significant difference between the sexes (t-test, p-value is 0.0264) and a general pattern of increasing Iy values across the age groups within each sex, though no statistically significant changes across age groups are noted (Figure 4.3).

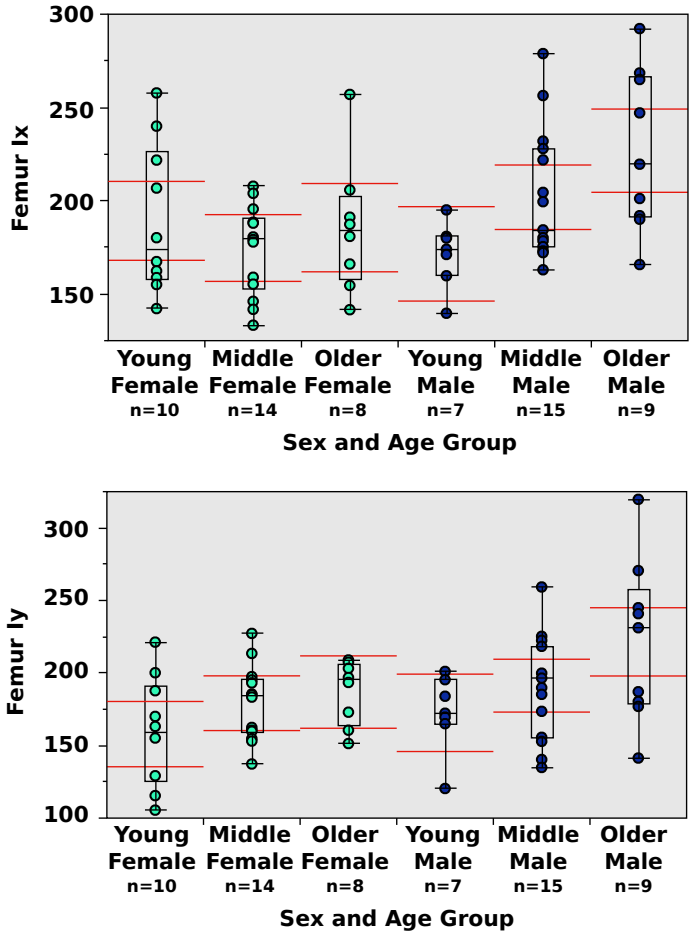

Figure 4.3: Femur Ix (top graph) and Iy (bottom graph) for Tibanica sample, grouped by sex (females in green circles; males in dark blue circles) and age groups (young: 18-29 years old; middle: 30-49 years; older 50+ years old). The red lines are the 95% confidence interval of the mean. For Ix measurements, the sexes are significantly different and males show a statistically significant increase with age while females show no age-related changes to femoral Ix. For Iy measurements, there is a significant difference between females and males and a pattern of age-related increase is noted (but not statistically significant).

Overall, males have larger femoral Imax values than females (statistically significant difference between the sexes, t-test p-value is 0.0159). Interestingly there is also an age-related increase in Imax for males but not for females. Male Imax values increase from young to old age, with these two groups having statistically significant different means (Tukey-Kramer HSD comparing Young and Older groups, p-value is 0.0047). Males have statistically significantly larger femoral Imin values than females (t-test p-value of 0.0276). There is a pattern of Imin increasing with age, with males again showing a statistically significant increase in Imin between the younger and older age categories (Wilcoxon rank sums paired comparison Young-Older p-value is 0.0262). Interestingly, there is also a pattern for female Imin increasing with age, though this is not statistically significant across the age groups.

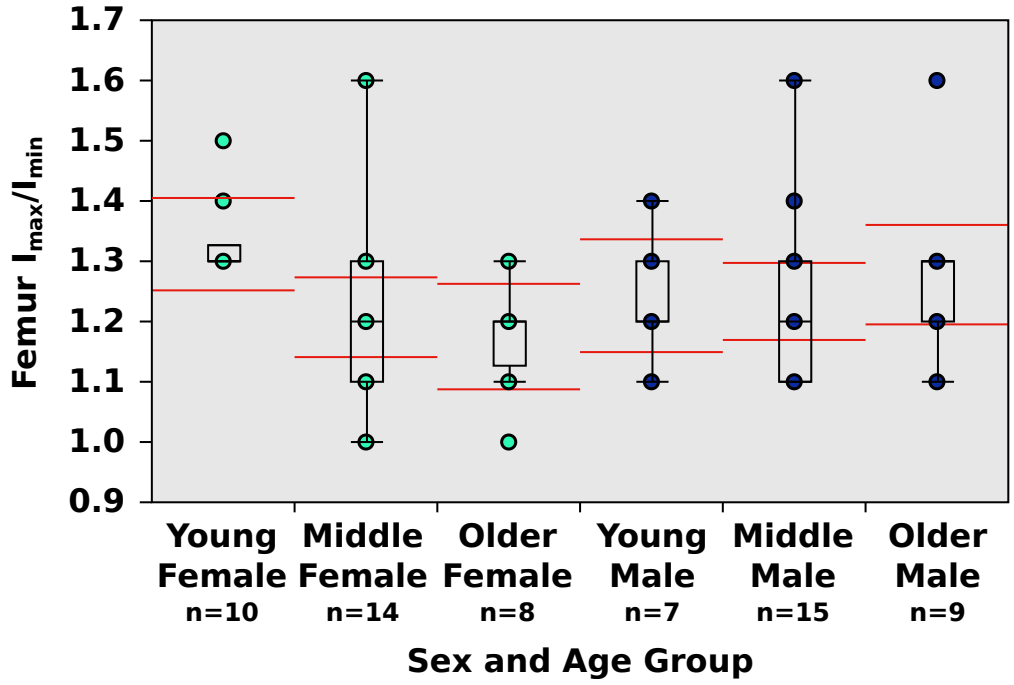

Figure 4.4: Femur Imax/Imin plotted with both age and sex groupings noted (females are green circles, males are blue circles). The age groupings are young (18-29 years old), middle (30-49 years), and older (50+ years old). Sample sizes are noted below each age and sex group (note that because these values are a ratio there are multiple points stacked on top of each other in many locations on the graph). The red lines are the 95% confidence interval of the mean. Note the significant shape change for females that occurs between young and middle age.

No statistically significant differences between females and male femurs are noted for either Ix/Iy or Imax/Imin (Table 4.3). However, within the females there is a statistically significant difference between the young and older age groups, with a noted decline in both the Imax/Imin and Ix/Iy value with increasing age (Figure 4.4). The youngest females have the highest mean Imax/Imin (mean of 1.3) and this is statistically different from the middle age group (Wilcoxon rank sum comparison Young-Middle p-

value of 0.0032; Dunn *post-hoc* joint ranking p-value of 0.0059) and from the older age group (Wilcoxon rank sum comparison Young-Older p-value of 0.0006; Dunn *post-hoc* joint ranking p-value of 0.0056). The femoral Ix/Iy data for the females follow the same significant age-related decline (Wilcoxon rank sum comparison Young-Middle p-value of 0.0007 and Dunn *post-hoc* joint ranking p-value of 0.0018; Wilcoxon rank sum comparison Young-Older p-value of 0.0043 and Dunn *post-hoc* joint ranking p-value of 0.0144). Males show no age-related changes to Ix/Iy or Imax/Imin.

Femoral J is significantly different between males and females, with males averaging almost 400 and females averaging 356.3 (t-test p-value = 0.0162; Figure 4.5; Table 4.3). Males also show a statistically significant increase in J as they age, with the means of the young and older age groups being significantly different from one another (Tukey Kramer HSD p-value of 0.0143 for this pair comparison). Female J shows a pattern of increasing across the age groups as well, though the increase is not statistically significant nor as dramatic as the male increase in J.

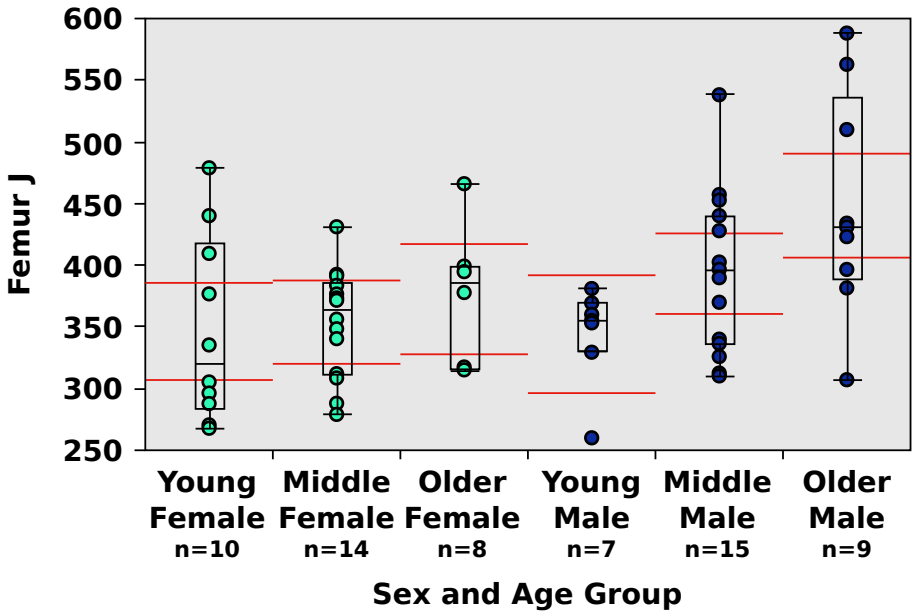

Figure 4.5: Femur J plotted by both age and sex (females are green circles on the left, males are blue circles on the right). The age groupings are young (18-29 years old), middle (30-49 years), and older (50+ years old). Sample sizes are noted below each age and sex group. The red lines are the 95% confidence interval of the mean. The second moment of area J is standardized by body size and bone length^2. Note the pattern of increasing J for both females and males with age, with males having statistically significant increases of J as they age.

Humerus

A total of 16 females and 17 males were analyzed for CSG humeral data. Overall, males show more bilateral asymmetry than females, but neither sex has a statistically significant side difference for any measure when comparing left and right humerii within each sex (Table 4.4). For all CSG measures females show a high degree of symmetry across the left and right upper arms (their asymmetry values are quite low), within the

range of 2-10%, in comparison to males whose absolute asymmetry (%AA) ranges from 3-16% (Figure 4.6). In most cases the female percent absolute asymmetry is half the size of the male value for the same CSG property. For example, female %AA for J is 7.7% while male J %AA is 15%.

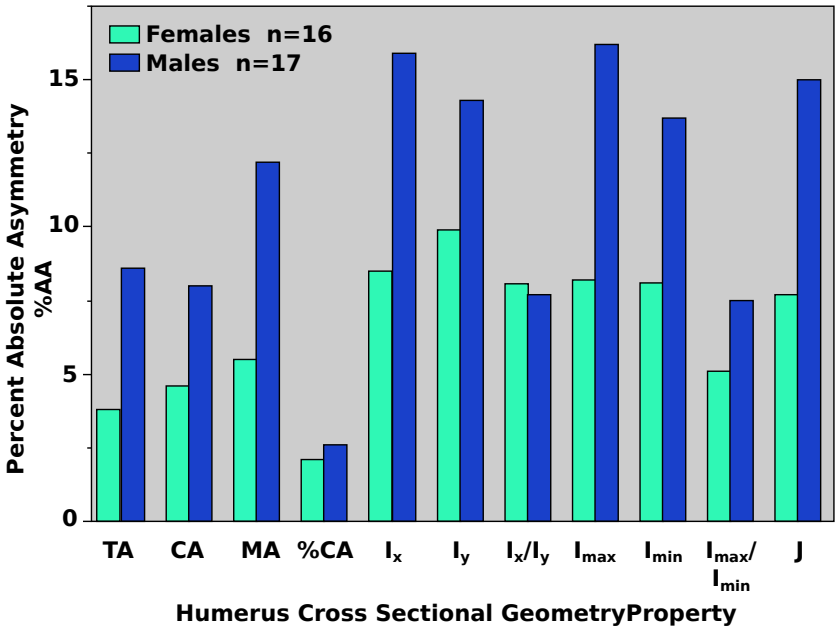

Figure 4.6: Paired bar plot showing percent absolute asymmetry (%AA) between left and right humerus bones for the same individuals, grouped by sex, for each cross-sectional geometry measurement. Female data are represented by green bars and male data are represented by blue bars. Note that for almost all measures females show much less asymmetry than the males do (except for Ix/Iy which is almost equal and relates to humeral shaft shape). The female data indicates strong symmetry between their arms while male data indicate right-hand dominance.

Percent sexual dimorphism is very high for many of the humeral measures (on both left and right sides), and consequently many of the cross-sectional variables for the Tibanica adults are statistically significantly different between the sexes. The female mean TA is 654.34 while the male mean TA is 516.88, indicating about a 27% sex difference between them (significant difference at alpha = 0.01 for both sides; Figure 4.7). For cortical area (CA) females are again larger than males (average of L & R side for females is 459.1, males average is 389.76; statistically significant difference at alpha = 0.05 for both sides). Males are significantly larger than females for %CA but only for the left humerus (t-test p-value of 0.0460; no significant difference on the right side). The medullary area in females is also larger than the males (statistically significant at the alpha = 0.01 level for the left side and alpha = 0.05 level for the right side).

Table 4.4: Tibanica humerus cross-sectional area measurements (total area, TA; cortical area, CA; percent cortical area, %CA; medullary area, MA) for both left and right arms, grouped by sex and age categories.

	FEMALES - LEFT HUMERUS			FEMALES _ RIGHT HUMERUS			Fem%AA	MALES - LEFT HUMERUS			MALES - RIGHT HUMERUS			Male%AA	% SEX DIFF	% SEX DIFF
	n	Mean	SD	n	Mean	SD	Females	n	Mean	SD	n	Mean	SD	Males	Left	Right
Total Area (TA)																
Combined Age Groups	16	652.0	147.5	16	656.7	129.1	3.8	17	494.8	110.1	17	539.0	116.6	8.6	31.8	21.9
Young (18 - 29 years)	6	588.4	142.0	6	607.8	129.4	4.9	5	460.9	138.5	5	497.3	131.0	8.3	27.7	22.2
Middle (30 - 49 years)	7	682.6	127.7	7	681.9	127.2	3.0	9	497.2	103.7	9	538.1	119.3	7.6	37.3	26.7
Older (50+ years)	3	707.5	209.2	3	695.9	192.9	3.7	3	544.2	94.8	3	611.1	72.7	12.1	30.0	13.9
Cortical Area (CA)																
Combined Age Groups	16	455.4	100.9	16	462.8	78.8	4.6	17	375.4	87.5	17	404.1	84.0	8.0	21.3	14.5
Young (18 - 29 years)	6	433.1	93.3	6	446.6	87.3	6.5	5	364.7	104.8	5	394.6	83.5	9.7	18.8	13.2
Middle (30 - 49 years)	7	481.3	115.6	7	483.2	86.4	3.7	9	372.7	65.4	9	398.2	77.7	6.4	29.1	21.3
Older (50+ years)	3	439.4	47.4	3	447.8	51.0	2.8	3	401.3	144.3	3	437.8	127.3	10.1	9.5	2.3
Percent Cortical Area (% CA)																
Combined Age Groups	16	70.7	7.6	16	71.2	7.3	2.1	17	76.2	7.6	17	75.7	8.0	2.6	7.7	6.3
Young (18 - 29 years)	6	74.1	5.2	6	73.9	5.8	2.0	5	79.5	4.0	5	80.3	4.8	2.6	7.3	8.6
Middle (30 - 49 years)	7	70.5	5.3	7	70.9	6.3	1.7	9	75.6	6.7	9	74.7	6.6	2.8	7.4	5.3
Older (50+ years)	3	64.6	13.1	3	66.6	12.0	3.2	3	72.5	14.3	3	71.0	14.1	1.9	12.2	6.7
Medullary Area (MA)																
Combined Age Groups	16	196.5	87.5	16	193.9	78.8	5.5	17	119.4	51.6	17	134.8	62.6	12.2	64.6	43.9
Young (18 - 29 years)	6	155.3	59.9	6	161.2	59.6	5.6	5	96.2	39.0	5	102.6	49.5	6.1	61.4	57.1
Middle (30 - 49 years)	7	201.2	55.6	7	198.8	56.8	5.0	9	124.5	54.9	9	139.9	60.9	13.6	61.6	42.1
Older (50+ years)	3	268.1	162.4	3	248.1	142.4	6.7	3	142.9	62.5	3	173.2	81.9	18.0	87.6	43.2

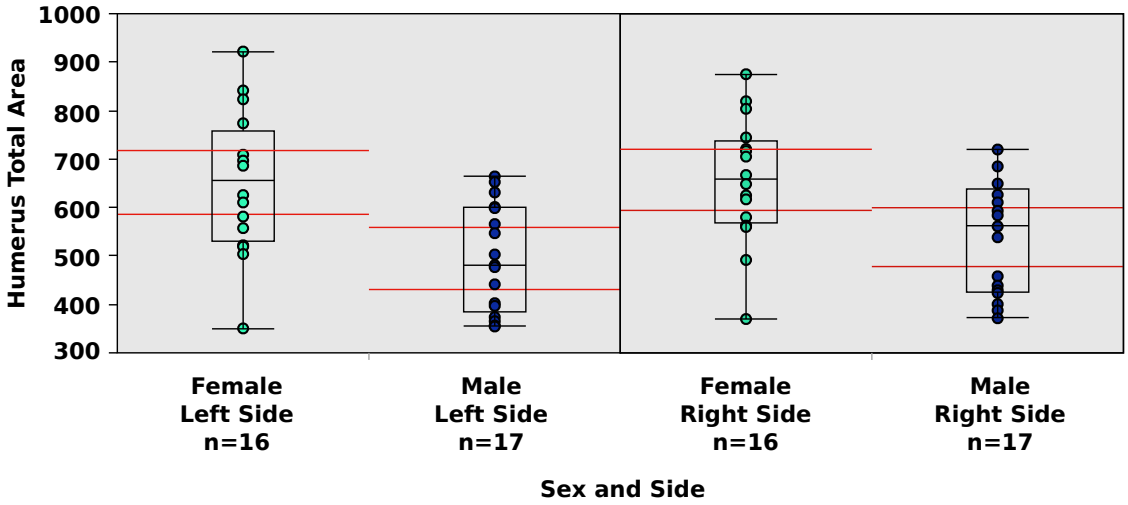

Figure 4.7: Humerus total area (TA) measurements for Tibanica females (green circles) and males (blue circles). The left humerus data is plotted on the left while the right humerus data is plotted on the right. Area measurements are standardized to correct for body size differences (divided by body mass estimate x 100). The red lines are the 95% confidence interval of the mean. Note that female total area is greater than males for both left and right arms.

Female data for left and right humeral Ix, Iy, Imax, and Imin are all statistically significantly larger than male averages for the same variables (and most of those are significant at both alpha =0.05 and 0.01; Table 4.5). There is no difference between the sexes for measures of humeral diaphyseal shape (Ix/Iy and Imax/Imin) and percent sexual dimorphism is the lowest observed in the sample for these variables. Male J values only reach about 60% of the female J values (male mean J = 274.7, female mean J = 422.6), with both sides showing statistically significant differences between the sexes at the alpha = 0.01 level (Fig 4.8)

Table 4.5: Tibanica humerus second moment of area measurements (Ix, Iy, Ix/Iy, Imax, Imin, Imax/Imin, J) for both left and right arms, grouped by sex and age categories.

	FEMALES - LEFT HUMERUS			FEMALES RIGHT HUMERUS			Fem%AA	MALES - LEFT HUMERUS			MALES - RIGHT HUMERUS			Male%AA	% SEX DIFF	% SEX DIFF
	n	Mean	SD	n	Mean	SD	Females	n	Mean	SD	n	Mean	SD	Males	Left	Right
Ix																
Combined Age Groups	16	211.5	82.8	16	207.8	68.1	8.5	17	128.1	64.3	17	148.7	70.9	15.9	65.1	39.7
Young (18 - 29 years)	6	180.4	82.5	6	190.9	79.4	10.3	5	119.9	75.3	5	135.9	73.6	16.4	50.4	40.4
Middle (30 - 49 years)	7	225.6	70.1	7	216.7	56.4	6.6	9	125.0	61.1	9	143.4	71.2	13.6	80.5	51.1
Older (50+ years)	3	240.5	121.8	3	220.6	89.9	9.3	3	150.9	76.5	3	185.6	80.9	22.2	59.4	18.9
Iy																
Combined Age Groups	16	209.3	78.7	16	216.6	104.6	9.9	17	126.9	58.9	17	145.7	64.7	14.3	64.9	48.6
Young (18 - 29 years)	6	183.2	80.9	6	192.5	70.1	11.5	5	114.1	78.6	5	128.0	78.8	13.3	60.5	50.4
Middle (30 - 49 years)	7	220.4	67.7	7	223.0	50.8	9.4	9	128.7	54.9	9	146.7	66.3	12.6	71.2	52.0
Older (50+ years)	3	235.6	113.4	3	249.9	123.8	8.0	3	142.7	50.6	3	172.3	40.2	20.9	65.1	45.1
Ix/Iy																
Combined Age Groups	16	1.0	0.1	16	1.0	0.1	8.1	17	1.0	0.1	17	1.0	0.2	7.7	0.0	5.2
Young (18 - 29 years)	6	1.0	0.1	6	1.0	0.1	4.7	5	1.1	0.1	5	1.1	0.1	9.6	11.7	12.0
Middle (30 - 49 years)	7	1.0	0.1	7	1.0	0.1	9.6	9	0.9	0.1	9	1.0	0.1	6.9	9.6	-0.1
Older (50+ years)	3	1.0	0.0	3	0.9	0.1	11.2	3	1.0	0.2	3	1.0	0.2	6.9	3.0	14.4
Imax																
Combined Age Groups	16	223.2	88.1	16	226.6	25.5	8.2	17	137.2	65.7	17	161.1	76.4	16.2	62.7	40.6
Young (18 - 29 years)	6	193.2	88.1	6	203.9	79.7	9.5	5	125.4	77.2	5	142.2	79.3	15.0	54.0	43.4
Middle (30 - 49 years)	7	237.1	74.6	7	233.2	54.9	7.5	9	136.1	61.7	9	157.8	77.0	13.8	74.3	47.7
Older (50+ years)	3	250.7	132.6	3	256.4	128.7	7.0	3	160.2	79.2	3	202.5	82.9	25.4	56.4	26.6
Imin																
Combined Age Groups	16	197.6	89.9	16	197.8	75.8	8.1	17	117.7	57.2	17	133.3	58.6	13.7	67.8	48.4
Young (18 - 29 years)	6	170.4	75.9	6	179.4	70.6	10.7	5	108.6	76.4	5	121.7	73.3	14.7	57.0	47.5
Middle (30 - 49 years)	7	209.0	61.9	7	206.6	51.3	6.3	9	117.6	54.1	9	132.3	59.9	12.0	77.7	56.1
Older (50+ years)	3	225.5	102.8	3	214.2	85.0	6.9	3	133.3	47.1	3	155.5	36.6	17.2	69.1	37.8
Imax/Imin																
Combined Age Groups	16	1.1	0.1	16	1.1	0.1	5.1	17	1.2	0.1	17	1.2	0.1	7.5	4.4	5.3
Young (18 - 29 years)	6	1.1	0.1	6	1.2	0.2	3.9	5	1.2	0.1	5	1.2	0.1	6.0	8.0	4.3
Middle (30 - 49 years)	7	1.1	0.1	7	1.1	0.0	5.3	9	1.2	0.1	9	1.2	0.1	8.1	3.5	3.5
Older (50+ years)	3	1.1	0.1	3	1.1	0.2	6.9	3	1.1	0.2	3	1.3	0.3	8.2	2.7	15.0
J																
Combined Age Groups	16	420.8	160.6	16	424.4	181.2	7.7	17	255.0	122.3	17	294.4	133.8	15.0	65.0	44.1
Young (18 - 29 years)	6	363.6	162.6	6	383.3	148.5	9.5	5	234.0	153.5	5	263.9	152.2	14.9	55.4	45.2
Middle (30 - 49 years)	7	446.0	135.9	7	439.7	106.2	6.5	9	253.7	115.4	9	290.1	136.5	12.8	75.8	51.6
Older (50+ years)	3	476.1	235.2	3	470.6	213.5	6.9	3	293.6	126.3	3	358.0	118.1	21.8	62.2	31.4

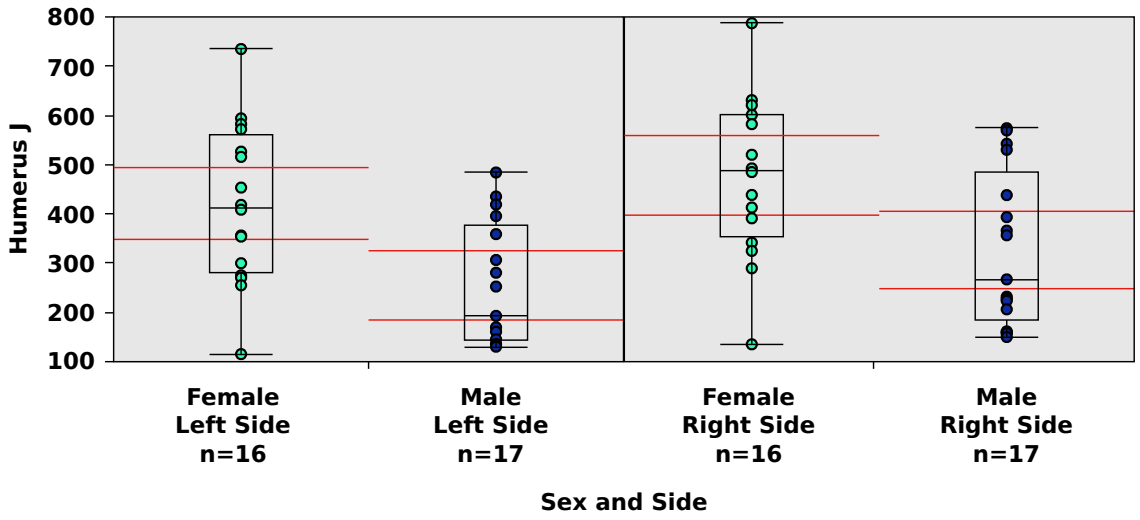

Figure 4.8: Humerus J measurements for Tibanica females (green circles) and males (blue circles). The left humerus data is plotted on the left while the right humerus data is plotted on the right. The J second moment of area measurement is standardized by body mass times bone length^2. The red lines are the 95% confidence interval of the mean. Note that the female J values for both left and right sides are significantly larger than male J values for both sides, indicating Tibanica female upper arm strength and robusticity was greater than males' (after correcting for body size differences).

Comparisons were also made within each sex across age groups (between young, middle, and older aged individuals). No statistically significant differences were found for any variable between the age groups (using Wilcoxon-Kruskal Wallis rank sums analysis). We recognize that small sample sizes limit the interpretation of age-related changes on the humeral cross-sectional properties reported here. However, we can look for patterns that may be associated with age-related changes to area measurements. For example, in Figure 4.9 we plotted the total area (TA), cortical area (CA) and medullary area (MA) measurements for the right humerus by both sex and age. We can see that cortical area (CA) is relatively stable over adulthood for both males and females, which is likely the result of total area increasing slightly with age while the medullary cavity also expands with age. We tested to see if removing older age individuals would change the effects between the sexes (i.e. are the six older individuals influencing the data in a significant way?) and we found that all statistically significant sex differences remain even with older individuals removed from analyses (so young and middle aged females still have larger values for TA, CA, MA, Ix, Iy, Imax, Imin, J than their age-matched male peers). Further studies with larger sample sizes can aid in distinguishing age-related changes to humeral bone morphology. In sum, the major differences we observe in humeral cross-sectional properties are between the sexes but we cannot rule out that some significant age-related changes may also occur but be statistically undetected in this sample.

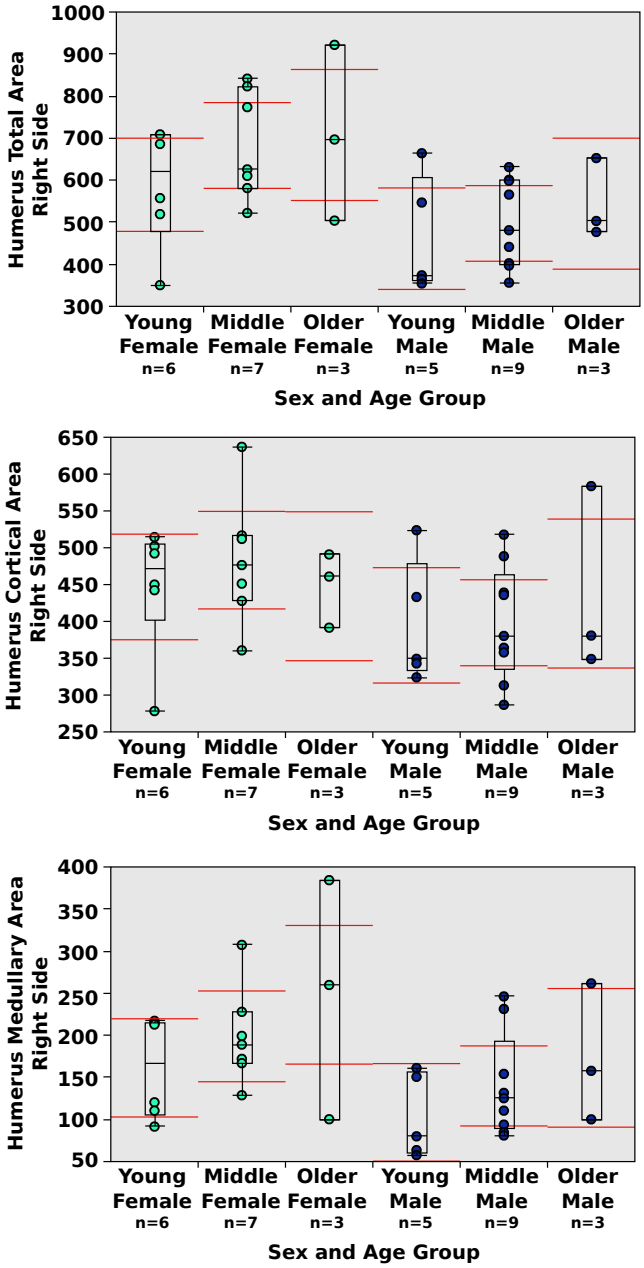

Figure 4.9: Total area (TA), cortical area (CA) for the right humerus (top graph) and medullary area (MA; bottom graph) is plotted by sex (females in green, males in dark blue) and by age groups (young: 18-29 years old; middle: 30-49 years; older: 50+ years). Total area appears to increase with age for both sexes. Medullary area also appears to increase with age for both males and females, related to endosteal bone loss with age.

Discussion

Femur

The CSG data from the femurs show different patterns between the sexes and across age groups, indicating some differences in activity that caused changes to the development and maintenance of bone structure and shape over their lifetimes. The Tibanica peoples' femoral CSG patterns are similar to other horticultural and agricultural populations (Ruff and Hayes, 1983b; Ruff, 2005; Wescott and Cunningham, 2006; Sparacello and Marchi, 2008). Females

have smaller bone area (TA, CA) at the mid-shaft cross-section than males. This is related both to sexual dimorphism (overall body size differences) but since the data is size-standardized the males generally have more robust femurs than the females, which is likely related to increased loading of the femur due to activity. Both sexes have similar femoral mid-shaft shapes when all age-groups are combined, suggesting similar mobility patterns and levels related to walking (Ruff and Larsen, 2014). Males have a significantly higher polar moment of inertia (J) than females, suggesting that there was some difference in the types of strain exerted on the lower limbs between the sexes, potentially linked to travel across rugged terrain or specific types of agricultural work such as use of digging sticks or other tools that use lower body force for males (Ruff, 1999, 2008).

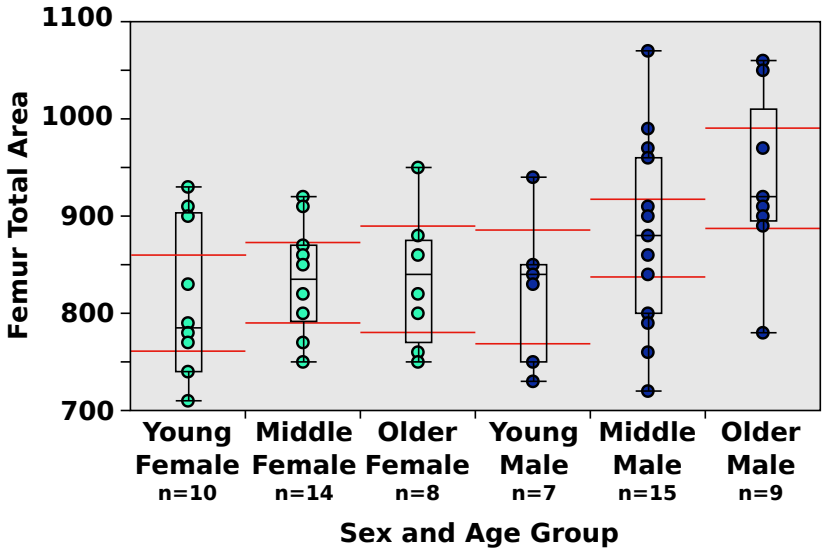

Figure 4.10: Femur total area (TA) plotted by both age and sex (females are green circles on the left, males are blue circles on the right). The age groupings are young (18-29 years old), middle (30-49 years), and older (50+ years old). Sample sizes are noted below each age and sex group. The red lines are the 95% confidence interval of the mean. Femur total area is standardized by body mass times 100. Note the striking pattern of TA increasing for males as they age, with a significant increase from young to old-age due to continual periosteal expansion.

Femoral TA increases for both females and males across the age groups, with the young individuals having the smallest TA and the oldest individuals having the highest TA (Figure 4.10). This pattern demonstrates the continued periosteal expansion with age, particularly for the males (though these changes are not significantly different across the age groups within each sex; (Ruff and Hayes, 1982, 1983b; Feik et al., 1996). Interestingly for females, femoral CA is highest in the young and middle age groups and declines in the older age females, while for the males the CA values continue to increase across the age groups, with the oldest males having the highest mean femur CA value (these are not statistically significant changes across the age groups but do show a pattern of age-related cortical changes, see Figure 4.11). When all combinations of sex and age were compared for total area (TA), there is a statistically significant difference between the Young Females and Older Males (Tukey-Kramer HSD p-value is 0.0076)

and between Middle Females and Older Males (Tukey-Kramer HSD p-value is 0.0224). As we can see in Figure 4.11, the greater amount of periosteal expansion in Tibanica males as they continued to age is what is driving this relationship between the age and sex groups: female femurs do not expand on the periosteal surface to the same degree that the males do as these individuals grow older (see discussions of age-related periosteal bone deposition in (Martin and Atkinson, 1977; Ruff and Hayes, 1982, 1988; Feik et al., 1996). This suggests that males are doing more habitual activities involving mechanical stress on their legs to cause more cortical bone to be laid down on their femurs, and that males are continuing these activity patterns into an older age than females, while females do not show the same degree of change to femoral total area as they age, suggesting less habitual mechanical loading of the femur throughout their lifetime.

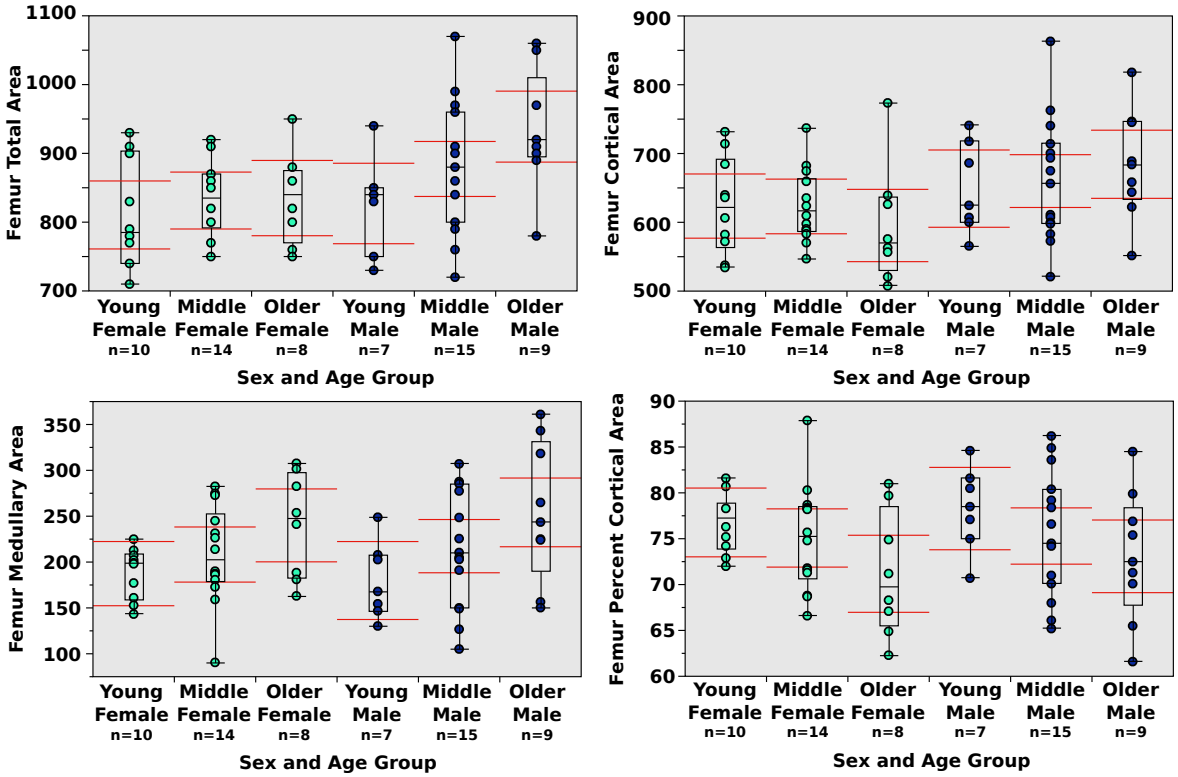

Figure 4.11: Femur cross-sectional area measurements plotted by sex and age groups (upper left: total area; upper right: cortical area; lower left: medullary area; lower right: percent cortical area). Females are represented by green circles; males are represented by dark blue circles. The age groupings are young (18-29 years old), middle (30-49 years), and older (50+ years old). Sample sizes are noted below each age and sex group. Red lines are the 95% confidence interval of the mean. Note that for both sexes total area and medullary area both increase with age, therefore cortical area and percent cortical area are relatively stable over the lifetime. Males show greater expansion of the periosteal surface (increasing TA over the lifetime) compared to females, likely a consequence of continual mechanical loading of the femur due to consistent activity.

There was no statistical difference between female and male femoral medullary area measurements or percent cortical area. The medullary area (MA) data shows the expected pattern of age-related expansion of the marrow cavity (see Figure 4.11), with the youngest individuals having the smallest MA for both sexes and this increases with age as bone is resorbed from the endosteal surface (however there are no statistically significant differences between the age groups within each sex but the general pattern is similar to many other populations, (Martin and Atkinson, 1977; Ruff and Hayes, 1982, 1983b; Feik et al., 1996). Therefore, for the Tibanica sample, bone strength may not be compromised as one ages, since the TA is expanding with periosteal acquisition, creating a larger cross-sectional diameter which increases the surface area across which a loading force can be distributed (Martin and Atkinson, 1977; Ruff and Hayes, 1982; Feik et al., 1996). However, for Tibanica older-age females, the increasing resorption of endosteal bone (MA expansion) is tied to a net loss in cortical bone (CA decline, %CA decline, though not statistically significant), which theoretically could compromise bone strength as the cortex thins with age (Martin and Atkinson, 1977; Ruff and Hayes, 1983b; Feik et al., 1996).

Femoral rigidity measures (I_x, I_y, I_{max}, and $I_{min)}$ show some sexual dimorphism, indeed the highest rates observed for femoral measures are on these variables (around 12%), and for males there is a statistically significant age-related increase in Ix and Imax. Younger males have lower I_x and I_{max} values than older males, suggesting that males may have been engaging in activities as they aged that caused a femoral response to increasing A-P bending, possibly related to greater mobility or traversing rugged terrain. Females do not show an age-related femoral change in I_x or I_{max}, suggesting that A-P bending rigidity is relatively constant over their lifetime. Ruff & Hayes (1983b) also found an increase in I_{max} with age, but across *both* Pecos Pueblo males and females, and they attributed this increase to subperisoteal expansion with age (increasing TA with age). For the Tibanica sample we see a general pattern of femoral TA increasing with age but this increase is more dramatic for males than females, explaining why the I_x and I_{max} values consequently change for males but not females. Similar to I_{max}, males have statistically significantly larger I_{min} values than females. There is a pattern I_{min} increasing with age, with males again showing a statistically significant increase in I_{min} between the younger and older age categories. Interestingly, there is also a pattern for female I_{min} increasing with age, though no statistically significant increase occurs across the age groups.

Stock and Shaw note that J "can be considered the most accurate and biomechanically meaningful estimation of bone strength" (Stock and Shaw, 2007:414). J is calculated from I_{max} and I_{min} data, and therefore has a similar pattern of sex and age related differences. Males show a statistically significant increase in femoral J as they age, while female J shows a pattern of increasing across the age groups as well, though the increase is not statistically significant (Figure 4.5). Therefore, males had more robust and stronger femur bones than females within the Tibanica population, and both groups (but males in particular) increased their femoral strength as they aged. This is again most likely related to the increasing total area expansion of the femoral shaft by the continual apposition of periosteal cortical bone as one ages. Especially for men, the increase in cross-sectional diameter results in subsequent increases in bone rigidity and strength. It is interesting to consider the processes of aging in this case, as one might expect strenuous activity levels to decline in older age. However, for both sexes consistent levels of activity (with possible increases in walking and agricultural activities for males) continue into older age.

The ratios of Ix/Iy and Imax/Imin are related to shape changes in the femur caused by loading events that distribute bone in response to A-P or M-L mechanical forces (Ruff, 2000a, 2008). These ratios have been used as markers of shape that may be associated with degrees of

mobility or habitual activity (Ruff and Hayes, 1983b; Larsen et al., 1995; Holt, 2003; Stock and Pfeiffer, 2004; Wescott and Cunningham, 2006; Stock et al., 2011; Pomeroy, 2013). Ratios with a value of close to 1.0 indicate a circular shape, while values above 1.0 deviate from circularity in the A-P direction while values below 1.0 suggest M-L loading patterns (Ruff and Hayes, 1983a; b; Wescott, 2006). The majority of Tibanica individuals (both sexes and across all age groups) have Imax/Imin values between 1.1 – 1.3, with the average for each sex around 1.2. These values indicate a mostly circular shape at the mid-shaft femur with slightly more influence from A-P directional loading, and these data are very similar to many other studies of both modern and archaeological human populations (Ruff and Hayes, 1983a; Wescott and Cunningham, 2006; Sparacello and Marchi, 2008; Pomeroy, 2013). There are a small number of individuals who deviate from this pattern and have higher Imax/Imin values, including 3 individuals (2 males, 1 female) with ratios of 1.6. These few individuals have significant elongation in the anterio-posterior plane. Some studies have suggested that high second moment of area ratios (Ix/Iy and Imax/Imin) are linked to long-distance mobility (Ruff and Hayes, 1983b; Ruff, 1987; Bridges, 1989; Stock and Pfeiffer, 2004; Stock, 2006; Maggiano et al., 2008; Shaw and Stock, 2009), while other studies have not identified a clear link between femoral mid-shaft shape features and degrees of sedentism/mobility (Wescott, 2006). These few individuals (one middle-aged female, one middle-aged male, and one older-aged male) who have much higher shape ratios were likely very mobile people, regularly walking very long distances, possibly related to resource procurement or trade.

Importantly for this study, no statistically significant differences between females and males were noted for either I_x/I_y or I_{max}/I_{min}: femoral mid-shaft shape is similar between the sexes for the Tibanica sample. This is important as sexual dimorphism in I_x/I_y has been interpreted as reflecting gendered patterns of mobility and we do not see this for Tibanica peoples - males and females had similar levels of mobility (Ruff, 1987). However, within the females there was a statistically significant difference between the age groups, with a noted decline in both the I_{max}/I_{min} and I_x/I_y value with increasing age, indicating significant shape changes occurred for females across their lifetime. Tibanica female femurs changed from a more A-P oriented femoral mid-shaft shape during early adulthood, to a more circular shaped one in older age. Interestingly, Feik et al. (2000) found that the mid-shaft femur becomes more circular as people age (true for both sexes), but particularly that young males have more A-P oriented femoral shape which then becomes more circular with age. Instead we observe that young women from Tibanica are engaged in more A-P loading tasks during youth, possibly related to traveling farther distances during adolescence and early adulthood. Then, as the Tibanica women aged, they did less of these tasks (maybe less long-distance walking) and their femurs consequently remodeled to a more circular shape with this change in activity pattern as they grew older. Since these changes are already noted in the middle age group (Tibanica young-middle age group comparison is statistically significant, Tukey-Kramer HSD p-value of 0.0002) then these activities must have slowed or ceased many years earlier (in order for the bone to remodel into the more-rounded shape it has in middle and older age). This finding is especially interesting as it indicates a change in activities that intersect with both age and sex, and opens up questions about what specific walking-oriented tasks adolescent/early adult aged females were engaged in that then stopped later in life (possibly agricultural work, herding, collecting fire wood, walking to resource areas to gather materials). We do not currently have answers to these questions but this data is intriguing and suggests a significant lifestyle change for females that is specifically correlated to age.

For the femoral CSG data overall we see that in males bending rigidity and strength increases as one ages, while for females bending rigidity and strength is relatively constant over the lifetime. This is a result of periosteal expansion increasing cortical bone diameter and therefore leading to a higher bending rigidity property in the femur mid-shaft, particularly for males. This continued bone growth is most likely related to habitual loading of the femur, spurring TA increase as one ages, suggesting that males may have been engaged in more strenuous lower body movements than females, and they may have been doing different activities that caused their femurs to continue to have significant appositional bone growth as they aged leading to more robust femurs than their female peers. We hypothesized that males would have CSG data corresponding to greater levels of robusticity and mobility than females, and the data support differences between the sexes for strength and robusticity, but not for overall mobility. We hypothesized age-related changes to the femur for both sexes, expecting to see older aged individuals declining in mobility (lower Ix/Iy and Imax/Imin values), but the data do not support this hypothesis for both sexes. The only group that shows age-related changes in mobility activity are the young females (whose data suggests high levels of mobility during youth), a group we did not anticipate standing out as statistically different from all other age and sex groups. Taken together, the femoral CSG data demonstrate that the Tibanica people were actively moving about their landscape (with a few individuals that were very mobile), and that males engaged in slightly more strenuous lower body activities than females, possibly walking longer distances to work with digging sticks in agricultural fields, traversing mountainous terrain in order to hunt, trade, collect firewood or gather other resources. Importantly, strenuous activities did not decline as people aged, the data suggests that older age individuals are often at the highest end of the range for femoral CSG variables, indicating continuation and sustainment of activity patterns at consistent levels over the lifetime (or possibly even greater activity in older age, such as seen with J).

Humerus

The humerii data provide insights into the activity patterns of females and males of the Tibanica community and show different loading patterns between the sexes, suggesting gendered activities. Humeral cross-sectional data are unique because the arms are not load-bearing limbs in the same way that our legs are; our upper arms are directly engaged in and responding to habitual tasks, and their morphology can show dramatic differences between arms if one limb is more actively used than the other (Stirland, 1993; Trinkaus et al., 1994; Weiss, 2003; Shaw and Stock, 2009, 2013). While the sample size presented here is not very large (n=33, females = 16, males = 17), the results have significant implications for divisions of work activities between the sexes. We predicted that males would have higher strength and robusticity measures for their humerii (following patterns observed in most populations). However, the data does not support this hypothesis; instead it encourages us to expand this study to see how female/male differences in humeral strength vary in time and space across South American populations. We also hypothesized that males and females would show similar levels of bilateral asymmetry, corresponding to hand-dominance in tasks. The data does not support this hypothesis, with females showing greater symmetry in the use of their arms, while the males show right-hand dominance.

When the cross-sectional geometry data are standardized to body size (as they are presented here) we see that females have very robust, strong upper arms, and for almost all CSG measures the females exhibit values that are significantly larger than their male peers. The levels

of sexual dimorphism are very high across many of the humeral CSG properties. For example, TA shows moderate to high sexual dimorphism at about 27% (females have statistically significantly larger mean TA than males), while J has extremely high sexual dimorphism at about 54%. Most previous studies of cross-sectional geometry data for adult humerii from prehistoric samples have reported data indicating male humerii and CSG properties are larger than females for CSG measures such as TA, CA, %CA, and J (Bridges, 1989; Weiss, 2003; Marchi et al., 2006, though note TA for females in LUP time period have larger values than males; Maggiano et al., 2008; Sparacello and Marchi, 2008; Sparacello et al., 2011). Few studies have noted such dramatically large values for female humeral CSG variables in comparison to males from the same population (though see Wescott and Cunningham, 2006; Ogilvie and Hilton, 2011). Weiss (2003:300) suggested that "relatively greater male upper-body strength is universal among human populations." The Tibanica females, with their strong upper bodies, would require modifying that generalization.

The Tibanica female humerii show larger TA and CA values than the males, the skeletal response to heavy usage and stressful mechanical loading causing increased periosteal bone deposition and retention of this bone over the lifetime due to habitual use. Males show humeral TA and CA patterns similar to their femurs but not as extreme, with TA and CA increasing slightly with age, suggesting sustained periosteal expansion as an individual gets older (though no statistically significant differences occur across the age groups for the humerus, see Figure 4.9). Females also show increasing TA values with age, suggesting that both the processes of aging and strenuous upper limb activities during adulthood spur bone development. It is interesting to note that even as young adults, female TA is higher than male TA, suggesting that female activities that cause robust humerus development begin during adolescence and continue throughout their adult life. It is likely that females achieve peak bone mass for the upper arms during early adulthood through repetitive, sustained activities, possibly from food preparation activities, spinning/weaving, and/or from carrying and lifting heavy things (which may have included care for children).

Both sexes show expansion of the humerus medullary cavity with age, as is expected with age-related bone loss (Martin and Atkinson, 1977; Ruff and Hayes, 1982), though no statistically significant difference in MA is observed between the age groups. While both sexes appear to be adding bone to the periosteal surface with age (see Figure 4.9), we do note that the medullary area may be increasing at a greater rate than total area is, potentially causing a net loss of bone as individuals reach older age (note the general pattern of decline in percent cortical area, though not statistically significant with sex or age groups, Figure 4.12). Future work with larger sample sizes will be able to better assess age-related changes to humerus cross-sectional properties.

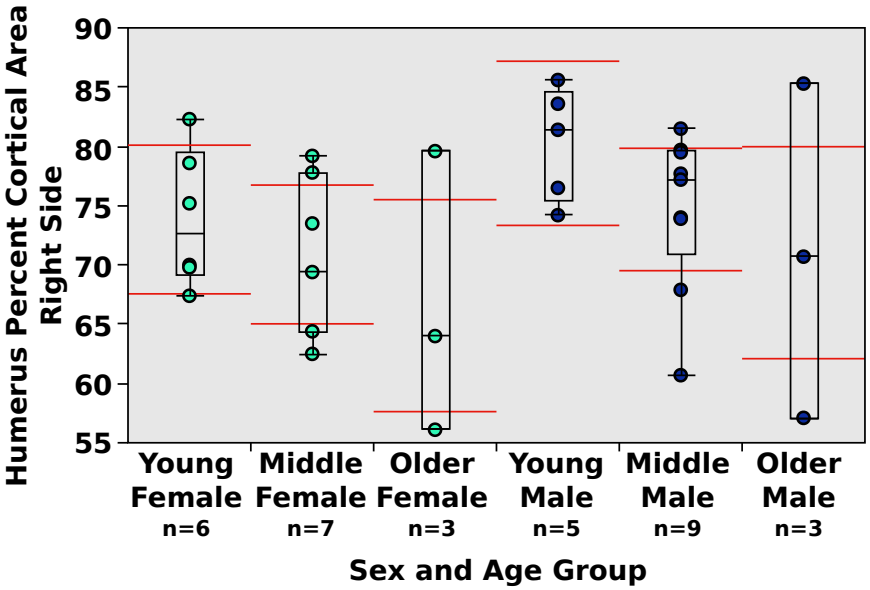

Figure 4.12: Right humerus percent cortical area (%CA) for both sexes (females as green circles, males as dark blue circles) and by age groups (young: 18-29 years old; middle: 30-49 years; older: 50+ years old). Sample sizes are noted below each age and sex group. Red lines are the 95% confidence interval of the mean. Note the pattern of age-related decline in %CA for both sexes, likely related to increasing medullary expansion with age.

Females have higher humeral bone strength and bending rigidity values than males (J, Ix, Iy, Imax, Imin), a function of the overall robusticity and distribution of bony matrix within their humerii. As noted above, female J (mean J of left and right J combined is 422.6) is much larger than male J (left and right J combined average is 274.7; t-test p-value significant at 0.01 alpha level) for the humerii. The higher J values observed in females are a product of the larger TA that female humerii have, but most significantly these further support the interpretation that Tibanica females were engaged in very demanding upper body labor consistently from an early age and throughout their entire lifetimes. On every humeral strength and robusticity measure male means are smaller than females; and while this does not suggest males were not actively engaged in labor and activities that exerted force on their upper arms, they just were not using them in the same mechanically strenuous ways that the females were. This suggests that women's work involved mechanically strenuous upper body movements (grinding, pounding, carrying, lifting) while men's work was more mechanically stressful for their lower bodies (walking, running, using digging sticks, possibly also squatting/lifting with strong leg engagement in those movements).

Females show little difference in CSG properties between their left and right arms for the CSG variables measured (2-10% absolute asymmetry). This symmetry in humeral strength demonstrates that they were consistently engaging both arms equally for tasks: one arm was not particularly dominant over another for most movements, as would be seen in pounding and grinding foods or in carrying children or other heavy loads. Males however show some difference between their left and right humerii, with their right arm having higher values for almost all variables (only %CA is higher on the left side), indicating that males perform tasks using their right arm more than their left. Taken together the data suggest males were engaged in

activities with right arm dominance, while females relied on both arms equally in their daily work.

Other studies have also noted populations with males showing a higher degree of bilateral asymmetry in the humerus while females had very low levels of asymmetry (see (Ruff and Jones, 1981; Fresia et al., 1990; Mays, 1999; Sládek et al., 2007; Sparacello and Marchi, 2008; Weiss, 2009 but only for the California Amerinds; Ogilvie and Hilton, 2011). Many of these studies linked female symmetry to activities related to food preparation such as grinding of grains or maize, and possibly to childcare. Grinding foods such as maize requires upper body movements that are very strenuous on the arms and require the use of both limbs equally. While these movements do not negate a general hand dominance that all humans display (especially for fine motor tasks), the consistent use of both arms for strenuous work would allow both humerii to respond and develop similar morphologies. Therefore, we suggest that Tibanica females are conducting the same types of intensive work, potentially with an emphasis on grinding maize, pounding manihot (yuca), or preparing other foods that require effort to break them down before consumption (Miller et al., In Press; Chapter 3 of this dissertation). Craftwork such as cotton spinning and textile production may also have been a significant part of women's daily work as well (de Zubiría, 1986) and further studies of the physical demands this work places on the body would provide important insights for biomechanical studies such as this (though see Weiss, 2009 for some discussion on sewing which is an asymmetrical/handed activity).

Conclusions

This biomechanical analysis of the Tibanica skeletal sample provides novel insights into the activity patterns of the ancient Muisca people. Previous archaeological studies of the Muisca have not looked for direct evidence of human labor patterns, most focusing on artifacts associated with general activities such as agriculture, hunting, weaving, craft production, and mining (Langebaek Rueda, 1987, 1995; Kruschek, 2003; Boada Rivas, 2007). Historical documents from the early colonial period provide little information on average peoples' lives and work activities, instead focusing on chiefs and high ranking individuals (Langebaek, 2014). For the Muisca in particular, historical documents emphasize the riches that the Europeans were seeking: gold, emeralds, other minerals such as copper and silver, salt and spices, and how the conquerors sought to attain these treasures rather than describing the mundane activities of Muisca daily life (Eidt, 1959; von Hagen, 1974; Langebaek, 2014). Therefore, these cross-sectional geometry analyses provide a new approach to understanding the lives of ancient Muisca starting from study of the individuals themselves.

Many researchers have raised important points about the limitations of interpreting cross-sectional geometric data (Lieberman et al., 2004; Meyer et al., 2011; Ruff and Larsen, 2014). Some of the major limitations of interpreting cross-sectional geometry data relate to confounding issues of genetic relationships, environmental factors, dietary and health histories, and these are easier to control for in intra-population studies rather than comparative population research. While the main focus of our study is on intra-population differences related to sex and age, we will compare resulting data to other populations within the discussion recognizing that such comparisons confound issues of genetic histories, diet/nutrition, etc. However, I feel that both intra- and inter-population comparisons of CSG data are an important step forward in studying how ancient people's bodies responded to the daily tasks that they endured.

The sample studied here may not be representative of all Muisca communities and may reflect specific, local activity patterns unique to the Tibanica community. Further analysis of other populations in the Andean highlands and from different time periods will help to place the findings presented here within a larger pre-Columbian context. However, the strong upper arms of females do spark intriguing questions and suggest consistently heavy workloads by Tibanica women. We cannot exclude the possibility that genetics are also an important factor that may be influencing humeral development, such that larger humerii may have been selected for within the genetic history of the Muisca peoples (Weiss, 2003). Further study examining humeral elements from other Muisca groups and other South American populations will aid in clarifying the role of activity versus genetic heritage.

Femoral data support previous research that most Muisca people were actively engaged in regular labor associated with agricultural production, with males having more robust femurs, related to more strenuous lower body activity. Males may have been walking to more distant fields or using agricultural tools that exerted more force on their legs (digging sticks, picks or hoes). The Sabana de Bogotá sits within the eastern cordillera of the Andes and males may have been climbing this rugged terrain with regularity, possibly related to hunting activities or procuring other resources such as fuel. Female femurs indicate similar amounts of walking as males, except during adolescence and early adulthood when young females' femoral mid-shaft shape reflects greater mobility. Here we see the intersection of multiple biosocial variables, as a particular amount of activity (increased running, walking or other movement that causes A-P femoral loading) was linked to being both a female and young, and this was an unexpected finding. Future studies of prehistoric biomechanics should aim to sample across a populations' complete age-range in order to look for these intersections.

The upper arm data for the Tibanica peoples suggest a gendered division of labor for particular tasks. Females have stronger and more robust humerii than males and show little asymmetry between their arms, suggesting they were very regularly engaged in strenuous activities such as grinding maize or pounding yuca. Males have less robust humerii and show right-hand dominance and while we hesitate to link these to specific activities, one can imagine a range of lateralized tasks, from using agricultural/fishing/hunting tools to more fine-grained work required of craft production such as textile painting or metalworking. Cumulatively these data present a picture of the daily lives of Muisca peoples: people led physically demanding lives, working hard into old age.

Much of the research that has been done on the Muisca has examined archaeological materials for evidence of social status and inequality. This study is unable to directly address if social status had consequential effects on a person's activity patterns because only a small number of individuals with grave goods were included in these analyses. The few individuals of high status that were included in this sample (status has been inferred by the presence of durable grave goods, see Bernal A. and Langebaek, 2012; Langebaek et al., 2012b), do not show any pattern that separates them from the general trends we see within their age and sex groups (they do not stand out on any particular measure as being an outlier or otherwise different). Future work comparing more individuals across various social status categories could greatly assist in clarifying if status and activity patterns were linked for Muisca peoples. Additional work should also examine populations that lived near salt and emerald mines located within Muisca territory to potentially document the effects that these specific types of labor may have had on individuals and their skeletons. The application of biomechanical analysis to more prehistoric South

American populations will provide valuable insights into the range of practices that shaped the everyday lives of *every body*.

Chapter 5: Bone Maintenance and Loss in a Muisca Population: The effects of sex and age

Introduction

The skeletal diseases osteopenia and osteoporosis (bone loss leading to fragility) affect millions of people around the world, particularly in populations living in Western nations (Riggs and Melton, 1995; Johnell and Kanis, 2006). There are many biological and cultural factors that relate to the development, maintenance, and loss of bone over the life cycle. Understanding these factors has become a central focus for studies tackling disease etiology and for public health experts looking for solutions to lower current rates of osteoporosis (Heaney et al., 2000; Agarwal and Stuart-Macadam, 2003; Beauchesne and Agarwal, 2014). Studying the skeletal remains of ancient human populations can help us investigate the phenomena of bone health in past societies and contribute a historical understanding to the causes of this now debilitating and costly disease today (Agarwal and Grynpas, 1996; Brickley and Agarwal, 2003).

Many factors affect the quantity (the actual amount of bone created and maintained) and quality (the material and structural properties) of bone that an individual has over his or her lifetime (Grynpas, 2003). The foods we consume provide the necessary elements for bone development and maintenance, and literally become the building blocks of bone (Kohn, 1999; Palacios, 2006). The type of physical activities we do that cause biomechanical stress to our bones allows them to respond and adapt to changing circumstances (Cullinane and Einhorn, 2002; Martin, 2003; Burr, 2004; Robling et al., 2006; Ruff et al., 2006). Hormonal changes that come with adolescence and normal aging, pregnancy, lactation, and menopause/andropause can dramatically alter our bones (Sowers, 1996; Rosen, 2002; Agarwal and Stuart-Macadam, 2003). Health status and exposure to pathogens can both directly and indirectly involve the skeletal system (Bridges, 1989; Brickley and Ives, 2008). The natural process of aging and remodeling our bones causes changes to the quantity and quality of bone that we maintain (Rosen, 2002; Frost, 2003; Stini, 2003).

Human bone remodels itself over the entire life of an individual and is never in a static-state (Martin, 2003; Hall, 2005). Remodeling serves to alter bone, usually functioning to replace bone that is fatigue-damaged or to provide the body with the calcium and phosphorus that it requires for metabolic needs (Ott, 2002; Parfitt, 2003). Repetitive or extreme mechanical loading is thought to be one of the most critical reasons that bone remodels (Cullinane and Einhorn, 2002; Martin, 2003; Burr, 2004; Ruff et al., 2006). Remodeling can maintain or change the amount of bone present, and ideally an equal amount of bone is replaced so that there is no net bone loss. However, sometimes these processes are unequal and there is a total loss or gain of bone (Parfitt, 2002, 2004). Total loss of bone in later life due to remodeling without replacement can lead to decreased bone mass and increased risk of fracture, associated with osteoporosis (Heaney, 2003; Parfitt, 2004).

Studies of osteoporosis in modern populations have identified particular groups that appear to have a higher risk of developing osteoporosis, with factors such as age and hormonal status playing important roles as possible mediators (Eddy et al., 1998; Frost, 2003; Seeman, 2003; Stini, 2003; Lin and Lane, 2004). Women are at the highest risk of developing osteopenia and osteoporosis, primarily related to hormonal changes with menopause (extreme drop in estrogen) and potentially cultural factors such as fewer pregnancies and births, and shortened or no lactation periods with children (Sowers, 1996; Agarwal and Stuart-Macadam, 2003). Other

clinical work has studied people with poor nutrition who are thought to have higher risk factors, particularly the elderly who tend to consume less protein, or are deficient in calcium and/or vitamin D (Rosen, 2002). These cultural factors, such as dietary changes for the elderly and changes to reproductive activities for women, have serious consequences on bone remodeling and maintenance of bone health. Bone quantity and quality are not only dictated by genetics, metabolic and physiological processes, but also by cultural influences that can modify these biological processes. Examination of bone loss and overall bone health in past populations is critical to understanding osteoporosis as the result of both biological and cultural factors, and the work of bioarchaeologists investigating skeletal health from a biocultural perspective can play an important role in modern medicine (Agarwal and Stuart-Macadam, 2003; Brickley and Agarwal, 2003). Few studies have examined skeletal health using metacarpal radiogrammetry methods in prehistoric populations, with no published studies of any pre-Columbian populations from South or North America. This study investigates patterns of bone development, maintenance, and loss measured in the second metacarpal from a Muisca population of the northern Andes of South America (AD 1000-1400). The Muisca are an ideal society to study because previous work has demonstrated important gender, age, and status differences, particularly related to food access and physical activity patterns (see Chapters 3 & 4, this dissertation). Therefore, this study will contribute novel data to the larger discussions of bone maintenance and loss in ancient populations (particularly providing data for an understudied area of the world) and will examine how age and sex affect skeletal health within this dynamic, hierarchical society. I hypothesize that bone health will mirror the findings of many modern populations, with bone loss occurring at higher rates for females especially during older age due to hormonal changes, while their male peers may lose bone but only with very old age and not as dramatically as the women. The results presented here are also compared with previously published archaeological samples and modern clinical data.

Previous Studies

The development and maintenance of bone over the lifetime is an important indicator of overall health status, particularly for bioarchaeologists studying ancient populations. Archaeological studies of bone loss due to metabolic stress have focused on age and sex differences in ancient populations (Mays, 1996, 2000, 2001, 2006; Glencross and Agarwal, 2011; Beauchesne and Agarwal, 2014). Cortical thickness in bones such as the metacarpal has been demonstrated to correlate strongly with bone loss at other skeletal sites and can therefore be used as a reliable indicator of overall bone health (Ives and Brickley, 2005; Haara et al., 2006). Rates of osteoporosis are especially high in Europe, Britain, and other Western countries. Consequently, many of the studies looking at bone health from a bone maintenance/loss perspective have focused on historic and archaeological populations from Europe.

The Imperial Roman population from Velia (1^{st}-2^{nd} century AD, Italy) was studied using metacarpal radiogrammetry and both sexes showed age-related bone loss (Beauchesne and Agarwal, 2014). Both sexes showed bone loss in older age, but females appear to lose bone quantity in middle age. The authors suggest this loss may be related to females who are pregnant and or lactating, dying during this period of life, therefore reflecting intermittent bone loss that would have been recovered if the woman had lived longer (Beauchesne & Agarwal, 2014). While bone loss is noted for older aged individuals at Velia, fracture rates are low, suggesting that other protective factors such as high levels of physical activity may have counteracted the loss of bone (Beauchesne & Agarwal, 2014).

Mays (2006) studied a 3rd-4th century AD population from Ancaster, England, using radiogrammetry of the second metacarpal of females and found significant bone loss, particularly in postmenopausal women (greater loss than the comparative modern reference population). High rates of fractures that are commonly associated with osteoporosis were also noted for the archaeological women, suggesting a link between bone loss and fracture risk (Mays, 2006). However, males were not included in this study so it is unclear if there are sex differences in bone development, maintenance, and loss for this population (Mays, 2006).

In the British Wharram Percy archaeological population (11th – 16th century AD), Mays (1996) found that female cortical bone index (CI) declines significantly in the second metacarpal between younger and older aged women, while male metacarpal CI did not change with age. This pattern is similar to modern clinical data for British and European women, with bone loss in older age associated with post-menopausal hormonal changes (Mays, 1996). However, Agarwal et al., (2004) also examined individuals from Wharram-Percy for trabecular architecture maintenance and loss in the vertebrae, and found patterns that were different from modern populations. The authors linked reproductive and hormonal factors to bone loss in females from this Medieval group (Agarwal et al., 2004). They suggest the women living during this time would likely have had high parity and extended periods of lactation leading to patterned bone loss through time related to these reproductive factors (Agarwal et al., 2004).

Another study of men and women from a British historic sample from Spitalfields (18th – 19th century AD) revealed that periosteal apposition continued throughout adulthood (Mays, 2000, 2001). However, with age, both males and females began to lose bone endosteally at a greater rate than the periosteal bone gain, leading to a net loss of cortical bone (Mays, 2000, 2001). This pattern of bone development and loss is similar to modern European age-related bone loss in both sexes, however, the archaeological populations do not have the associated high rates of bone fracture observed in modern females (Mays, 2000, 2001). These archaeological and historical European studies show different patterns of bone maintenance and loss for women and men of varying ages. The results demonstrate that skeletal health is a complex product of numerous biological and cultural factors which differentially effect human populations through time and space.

While hip fractures and osteoporosis are relatively low in modern South American populations in comparison to other parts of the world, fracture rates do appear to be rising in these populations, with clinicians calling for increased research to study emerging disease patterns (Mautalen and Pumarino, 1997; Morales-Torres et al., 2004; Handa et al., 2008). Hip fracture rates for the modern Colombian population are estimated at 175.5 per 100,000 persons aged 50+ years, with women almost twice as likely as men to have a hip fracture (data reported in Morales-Torres et al. (2004) derived from Carmona (1999). A study of modern Colombian women from Bogotá aged 45-75 years, using dual-energy X-ray absorptiometry (DXA), showed age-related bone loss in the lumbar spine and femoral neck, and these women were also much lower in bone mineral density (BMD) of the spine than other South American modern populations (Villegas et al., 1995).

A clinical study focusing on the effects of pregnancy and associated fracture risk examined multiparous Colombian women from Barranquilla and found that women who were nulliparous had lower BMD and a greater risk of bone fracture compared to women who had at least one delivery (Cure-Cure et al., 2002). Bone mineral content and total body calcium increased for the women with each pregnancy, and these findings suggest that for this modern Colombian population, pregnancy protects females against bone loss and osteoporosis (Cure-

Cure et al., 2002). Another study of women from the same Colombian group found that lactation did not have any long-term negative effects on bone health (Cure et al., 1998). However, Londono and collaborators (2013) found premenopausal Colombian women living in poverty have higher rates of osteopenia and osteoporosis (women were aged 35-53 years old), suggesting that lifestyle factors, such as malnutrition and low birth weight, play an important role in the mediation of this disease (Londono et al., 2013).

From these studies we can see that the etiology of osteopenia and osteoporosis in modern-day Colombian populations is incredibly multi-faceted and may even be conflicting in places. It is also important to remember that the modern Colombian population is very diverse, with Indigenous, African, European, and Asian genetic admixture from migratory waves over centuries, therefore genetics may also play a role in the complex etiology of the Colombian expression of osteopenia and osteoporosis (Morales-Torres et al., 2004). Very little has been published on modern South American Indigenous groups, with Mautalen and Pumarino (1997) noting in their paper on osteoporosis in modern South America, "the bone status of the Indian population is, with few exceptions, practically unknown" (Mautalen and Pumarino, 1997:73). These emerging studies of modern South American populations raise the question of what pre-Columbian skeletal health was like in the past for this part of the world. Studies comparing modern and archaeological populations from different parts of South America could examine bone loss across these groups and in relation to age, sex, and lifestyle factors (diet, parity/lactation, physical activity patterns). To date, no studies have published cortical area measurements of the metacarpal for pre-Columbian Native American groups, therefore our study is limited in its comparative scope for this region of the world.

While no studies have focused explicitly on metabolic bone loss, some studies have examined pre-Columbian Native American populations for evidence of skeletal health in relation to dietary patterns and physical activity (Ericksen, 1976; Ruff et al., 1984; Bridges, 1989; Lazenby, 1997). Archaeological studies examined cortical thickness, bone mineral density (BMD), and bone mineral content (BMC) of skeletons from Yupik and Inupiaq speaking Inuit groups spanning 1000 years (Thompson and Gunness-Hey, 1981). All males had thicker cortices than females, and all the Inuit groups studied had thinner cortices when compared to modern whites from the U.S.A. Within the Inuit populations, Yupik peoples showed greater cortical thickness than the Inupiaq, and the researchers suggest that both dietary and activity differences between these cultural groups may be contributing to the differences in their cortical measurements (Thompson and Gunness-Hey, 1981). Lazenby (1997) follows up on this work by correcting for body mass within these populations and finds that there is still a real difference between populations. He proposes that bone loss in arctic populations is related to elevated production of thyroid hormones used in adaptation to cold environments (Lazenby, 1997).

North American Indian populations have also been studied, particularly for the examination of the effects of agricultural life and increased sedentism. For example, Bridges (1989) compared femoral and humerii data from Mississippian maize agriculturalists (AD 1200-1500) to hunter-gatherer Archaic Indians (6000-1000 BC). She observed changes to cortical bone area between these two populations, between the different sites (femur vs humerus), and between males and females. This study does mention the possibility that pregnancy and lactation might contribute to some of the unusual findings for females who show retention of bone strength despite decreased bone area (Bridges, 1989:790).

A study by Perzigian (1973) expected to note differences in bone health between hunter-gatherer Indian Knoll (2500 – 2000 BC) and the Hopewell (50 BC – AD 250) who supplemented

hunting and gathering with some agriculture. Additional evidence of these populations' diets from archaeobotany and faunal data indicate the Hopewell diet was more nutritionally adequate and consistent. Despite this nutritional advantage, the Hopewells lost more bone at a faster rate than the Indian Knoll sample. This finding was counter to Pezigian's expectations that a better diet (particularly protein-calorie sufficiency) would play a significant role in bone health and protect against bone loss (Perzigian, 1973). Unfortunately, the study did not address other factors that may be influencing these observed changes in bone health, such as the changes to activity patterns that are known to accompany transitions to agricultural lifestyles.

Two studies compared Inuit, Pueblo, and Arikara Native American populations to examine age and sex-related effects on bone (Ericksen, 1976) and whether bone remodeling was affected by dietary factors (Richman et al., 1979). Ericksen observed patterns of bone loss between these three indigenous groups and believes that despite genetic differences, the observed variation is actually the result of the interplay of different environmental factors, diets that relied on particular food staples, and different physical activities related to daily life (Ericksen, 1976). Richman and co-authors examined rates of remodeling in the same three native groups and found Inuits display higher rates of type II remodeling cavities than the other groups possibly due to their high protein diet, which may cause metabolic acidosis. The authors noted that exercise and or environmental effects were not assessed but may be important to understanding remodeling rates (Richman et al., 1979).

While many South American pre-Columbian populations have been studied by bioarchaeologists, few have focused on metabolic bone disease and the relationships between sex and age with skeletal health (Verano, 1997a; b; Knudson and Buikstra, 2007; Torres-Rouff, 2008; Klaus et al., 2009; Berryman, 2010; Klaus et al., 2010; Turner et al., 2010; Toyne, 2011; Arkush and Tung, 2013; Somerville et al., 2015). This study will examine how sex and age may have been mediating factors in maintenance and loss of bone for people living in a prehistoric Muisca community. This project provides new data on metabolic bone loss for this part of the world and will compare it to previously published studies from other sites. Stable isotope studies of the diets of Tibanica residents have indicated a gender division in food, with females consuming less maize and slightly less protein than males during adulthood, suggesting that nutrition may have also differed between the sexes (see Chapter 3, this dissertation). Historical documents note that many agricultural activities were the work of men while women were noted to be very active weavers (de Zubiría, 1986; Rojas de Perdomo, 1994). Recent work by Miller (Chapter 4, this dissertation), indicates a gendered division of labor with male work emphasizing lower body strength while females performed demanding work with their upper bodies. These gender differences for activity and diet make the Muisca peoples from the Tibanica archaeological site an interesting population to study the synergistic effects of diet and activity on skeletal health in conjunction with the biosocial variables of sex and age.

Materials & Methods

Cortical bone in the metacarpal can be quantified using non-destructive radiogrammetry methods. An advantage to this method is the ability of radiogrammetry to detect changes to bone quantity in the subjects under study (both in diachronic and synchronic study designs; Nielsen, 2001). Studies have shown metacarpal radiogrammetry to be a proxy for bone health status of other skeletal sites including the hip (Adami et al., 1996; Dey et al., 2000; Boonen et al., 2005), radius and ulna (Adami et al., 1996; Dey et al., 2000), and spine (Meema and Meindok, 1992; Wishart et al., 1993; Boonen et al., 2005). This method was developed in a modern clinical

setting to assess fracture risk (Barnett and Nordin, 1960), although technological developments in subsequent years have seen the rise of dual x-ray absorptiometry (DXA) as the standard tool for assessing osteopenia and osteoporosis in modern-day patients (Blake and Fogelman, 2007; Curtis et al., 2009). Archaeologists have been able to utilize metacarpal radiogrammetry as a low-cost, non-destructive tool for assessing bone quantity, especially in parts of the world where other forms of imaging technology are not available (Dey et al., 2000; Montalbán Sánchez et al., 2001; Nielsen, 2001; Boonen et al., 2005).

Table 5.1: Tibanica metacarpal radiogrammetry sample information by sex and age groups (n=75)

Age Group	Females	Males	Total
18-29 Years	9	6	15
30-49 Years	14	27	41
50+ Years	8	11	19
Total	31	44	75

Complete second metacarpals are required for radiogrammetry analysis and therefore sample size is often limited due to differential preservation of the hand bones. Adult individuals with well-preserved second metacarpals were identified within the Tibanica archaeological collection and sex and age-at-death were assessed by morphological features of the pelvis and skull (Lovejoy, 1985; Lovejoy et al., 1985; Brooks and Suchey, 1990; Buikstra and Ubelaker, 1994). Twelve individuals had both a left and a right second metacarpal and were analyzed to check for potential effects of side difference/handedness (n=5 females, 7 males). No statistically significant differences were found between left and right sides for TL, TW, or MW. Therefore, I was able to select individuals that had either left or right metacarpals, so that for the Tibanica sample a total of 75 individuals could be analyzed. Of those 75 individuals, 31 are females, 44 are males and span young (18-29 years old at death), middle (30-49 years of age at death), and older (50+ years old at death) age categories (see Table 5.1).

Metacarpals were x-rayed at the UC Berkeley University Health Services center using a Philips DigitalDiagnost 3.0 machine (settings: 55 kV, 1.2 mAS, 83.3 ms). Metacarpals were placed in a soft foam pad that had slits cut, allowing for each bone to be oriented in anatomical anterior-posterior position (Ives and Brickley, 2004). Digital x-ray files (dicom images) were created and ImageJ software (US National Institute of Health; Schneider et al., 2012) was used for measuring the bones. Previous work (Miller et al., in prep) has indicated that digital radiogrammetry analysis (using digitally produced x-ray images and digital measurement with ImageJ software) produces results that are comparable to the older film x-ray method (where manual measurements on film x-rays are performed using sliding calipers). No statistically significant differences were found between a set of samples that were analyzed using both film and digital x-ray technologies and measurement tools, with very high correlation between all measures (TL, TW, MW; Miller et al., in prep). Therefore, our digital results can be compared to previously published works that utilized traditional film x-ray measurements. Inter- and intra-observer error was assessed by paired sample t-tests on all 75 individual's metacarpals and across multiple periods of measurement. No statistically significant differences were found between observers or between repeat measurements by the same observer.

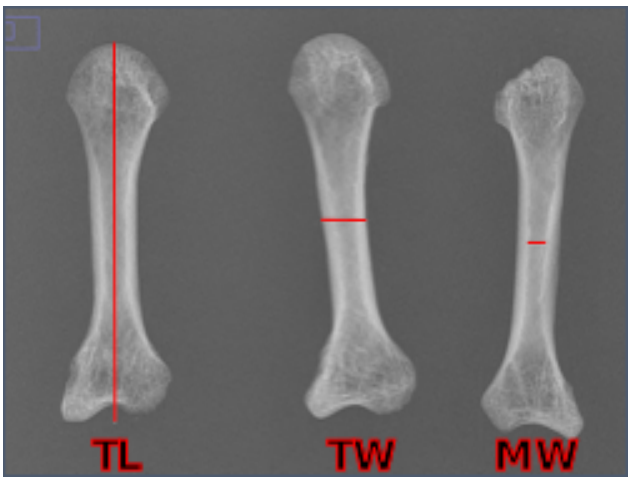

Figure 5.1: Examples of how total length (TL), total width (TW), and medullary width (MW) are measured on radiographs of second metacarpals from the Tibanica sample.

Metacarpal measurements follow standard protocols (Mays, 1996; Ives and Brickley, 2004; Glencross and Agarwal, 2011) and include total length (TL), total width at the midpoint (TW), and medullary width (MW) at the midpoint (see Figure 5.1). From these measurements all other indices are calculated including:

cortical thickness (CT)	CT = TW – MW
cortical index (CI)	CI = ((TW – MW)/TW) x 100
cortical thickness index (CTI)	CTI = ((TW – MW)/TL) x 100
medullary width index (MWI)	MWI = (MW/TL) x 100

The addition of CTI and MWI to this study is necessary due to the sexual dimorphism (overall size differences) observed between men and women from Tibanica (see results below; Glencross & Agarwal, 2011). Data was analyzed using the statistical package JMP Pro 12 (SAS Institute Inc.) with a significance level of 0.05. All measurements are from a normal distribution, therefore ANOVA and Tukey honestly significant difference (Tukey HSD) post-hoc tests were used to compare groups.

Results

Two-way ANOVA tests were used to examine the effects of sex and age and their interaction on all metacarpal measurements and indices. Sex has a strong association for two of the metacarpal size measurements: total length (TL; $p < 0.0001$) and total width (TW; $p < 0.0001$), indicating that sexual dimorphism is significant in the hand bone for this Muisca population (see Table 5.2, and Figure 5.2). Given the significant size difference between males and females, this study includes the measurements of MWI and CTI which take into account bone size in their calculations. Age-related effects were found for medullary width (MW; $p = 0.0026$), cortical index (CI; $p < 0.0001$), medullary width index (MWI; $p = 0.0003$), and the cortical thickness index (CTI; $p = 0.0002$). Only cortical thickness (CT) had effects of both sex

($p = 0.0001$) and age ($p < 0.0001$), but CT does not take into account the significant size differences between males and females, suggesting that age has a greater effect once sexual dimorphism is accounted for. Given these results, we first explored each sex separately looking at bone changes with age, and then compared the sexes within each age group using ANOVA and post hoc Tukey's honestly significant difference (Tukey HSD) tests. Results across sex and age groups are presented in Tables 5.2 and 5.3.

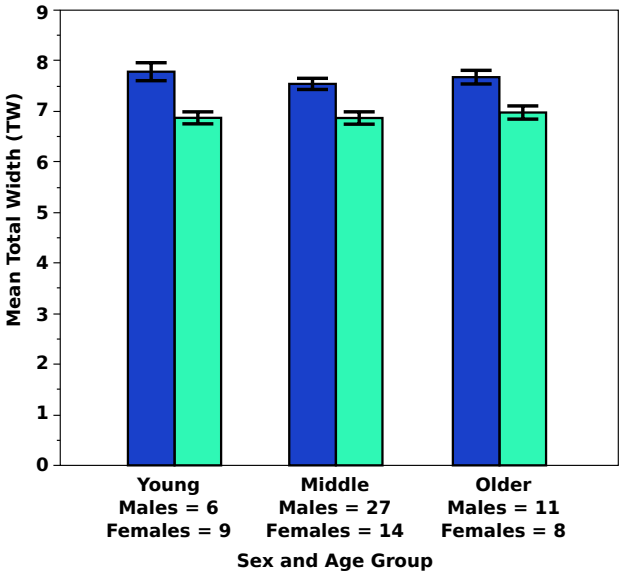

Figure 5.2: Mean total width (TW) for Tibanica population plotted by sex and age groups. Error bars are one standard error of the mean. Male means are plotted in dark blue; female means are plotted in green. Age groups are young (18-29 years), middle (30-49 years), older (50+ years). Overall, male TW is significantly larger than female TW. Within each sex there are no changes to bone width across age groups, indicating no periosteal expansion with age.

Within each sex, no differences were found in total length or total width across the age groups (so maximum bone length and width are achieved by both sexes by early adulthood, see Figure 5.2). The lack of change in bone width demonstrates that cortical bone was not added to the periosteal surface as individuals aged. For medullary width there are statistically significant differences for females between the young (18-29 years) and older (50+ years) age groups (Tukey's HSD $p = 0.0040$), while for males there is no statistical difference between age groups for MW (Figure 5.3). When we compared these results to the medullary width index (which standardizes values by bone length) we see that females are still significantly different between young and older ages (Tukey HSD $p = 0.0018$), and then males do show a (just barely) significant difference between young and older ages (Tukey HSD $p = 0.0467$). For females, medullary width changes with age, with a significant change in MW and MWI into older age. Males do not show the same degree of medullary expansion with age, indicating greater preservation of their cortex on the endosteal surface. Females had smaller MW than males on average within each age group, though this is not a significant difference (see Tables 5.2 and 5.3). By comparison, middle and older age females have greater MWI values than their age-matched male peers (though not statistically different).

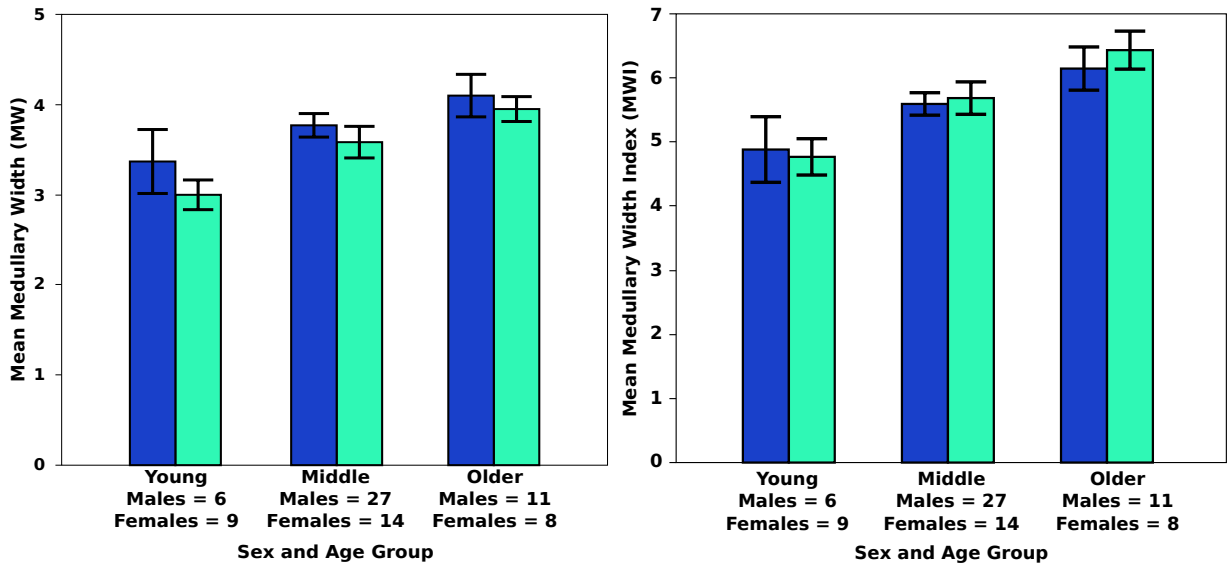

Figure 5.3: Mean medullary width (MW, left graph) and mean medullary width index (MWI, right graph) are plotted for each age and sex group. Error bars are one standard error of the mean. Male means are plotted in dark blue; female means are plotted in green. Age groups are young (18-29 years), middle (30-49 years), older (50+ years). There are no statistical differences between males and females within each age group. For both males and females there is an age-related statistically significant difference between young vs older age groups for MWI, while only females have a significant difference with age for MW (young vs older; significant at $p < 0.05$).

For cortical index, both sexes show age-related changes (Figure 5.4). Tibanica females have statistically significantly larger CI in younger age compared to both middle aged females (Tukey HSD $p = 0.0139$) and older aged females (Tukey HSD $p = 0.0009$). Males show a significant difference in CI between young and older age (Tukey HSD $p = 0.0347$). Cortical thickness measurements show similar patterns across age categories within each sex. Male CT is significantly larger in young age compared to middle aged males (Tukey HSD $p = 0.0289$) and compared to older age males (Tukey HSD $p = 0.0094$). The young-aged females also have significantly larger CT values compared to middle aged females (Tukey HSD $p = 0.0111$) and older aged females (Tukey HSD $p = 0.0013$). The cortical thickness index (CTI) which standardizes CT values by bone length, shows the same pattern for females, but a slightly different one for males. Within females, younger and middle aged groups are different (Tukey HSD $p = 0.0199$) and younger and older aged groups are different (Tukey HSD $p = 0.0055$), while for males only the younger and older age groups are statistically different (Tukey HSD $p = 0.0345$).

Table 5.2: Tibanica metacarpal measurements by sex and age. Note that the medullary width index (MWI) and cortical thickness index (CTI) are calculated following Glencross & Agarwal 2011 to account for size differences within this population.

Sex and Age Groups	Total Length (TL)			Total Width (TW)			Medullary Width (MW)			Medullary Width Index*			Cortical Index (CI)			Cortical Thickness (CT)			Cortical Thickness Index*		
	Mean	SD	SE of Mean	Mean	SD	SE of Mean	Mean	SD	SE of Mean	Mean	SD	SE of Mean	Mean	SD	SE of Mean	Mean	SD	SE of Mean	Mean	SD	SE of Mean
Females																					
Young (18-29 years) n = 9	62.97	2.02	0.67	6.87	0.36	0.12	3	0.49	0.16	4.77	0.85	0.28	56.61	5.09	1.7	3.88	0.18	0.06	6.16	0.27	0.09
Middle (30-49 years) n = 14	62.92	2.97	0.79	6.87	0.46	0.12	3.58	0.66	0.18	5.69	0.95	0.25	47.98	7.84	2.09	3.29	0.52	0.14	5.24	0.89	0.24
Older (50+ years) n = 8	61.68	4.43	1.57	6.98	0.37	0.13	3.95	0.39	0.14	6.43	0.84	0.3	43.31	5.79	2.05	3.03	0.49	0.17	4.92	0.81	0.29
ANOVA	NS			NS			18-29 vs 50+			18-29 vs 50+			18-29 vs 30-49			18-29 vs 30-49			18-29 vs 30-49		
													18-29 vs 50+			18-29 vs 50+			18-29 vs 50+		
Males																					
Young (18-29 years) n = 6	69.07	3.88	1.59	7.78	0.44	0.18	3.37	0.87	0.35	4.88	1.25	0.51	57.01	9.81	4.01	4.41	0.6	0.25	6.41	0.97	0.39
Middle (30-49 years) n = 27	67.3	3.18	0.61	7.54	0.57	0.11	3.77	0.68	0.13	5.59	0.91	0.18	50.18	7.21	1.39	3.77	0.53	0.1	5.61	0.77	0.15
Older (50+ years) n = 11	66.68	2.26	0.68	7.68	0.45	0.13	4.1	0.78	0.24	6.15	1.12	0.34	46.86	7.84	2.36	3.57	0.49	0.15	5.37	0.76	0.23
ANOVA	NS			NS			NS			18-29 vs 50+			18-29 vs 50+			18-29 vs 30-49			18-29 vs 50+		
																18-29 vs 50+					

Table 5.3: Sex differences in cortical bone measures within same-age cohorts. Statistical significance is measured at the 0.05 level using Student's t-test and indicated by a star. Note significant differences are only observed in TL, TW, and CT.

	TL*	TW*	MW	MWI	CI	CT*	CTI
18-29 Years							
Females n = 9	p = 0.0015*	p = 0.0006*	p = 0.3101	p = 0.8354	p = 0.9195	p = 0.0241*	p = 0.4607
Males n = 6							
30-49 Years							
Females n = 14	p = 0.0001*	p = 0.0005*	p = 0.4030	p = 0.7655	p = 0.3741	p = 0.0080*	p = 0.1683
Males n = 27							
50+ Years							
Females n = 8	p = 0.0049*	p = 0.0022*	p = 0.6279	p = 0.5494	p = 0.2954	p = 0.0269*	p = 0.2325
Males n = 11							

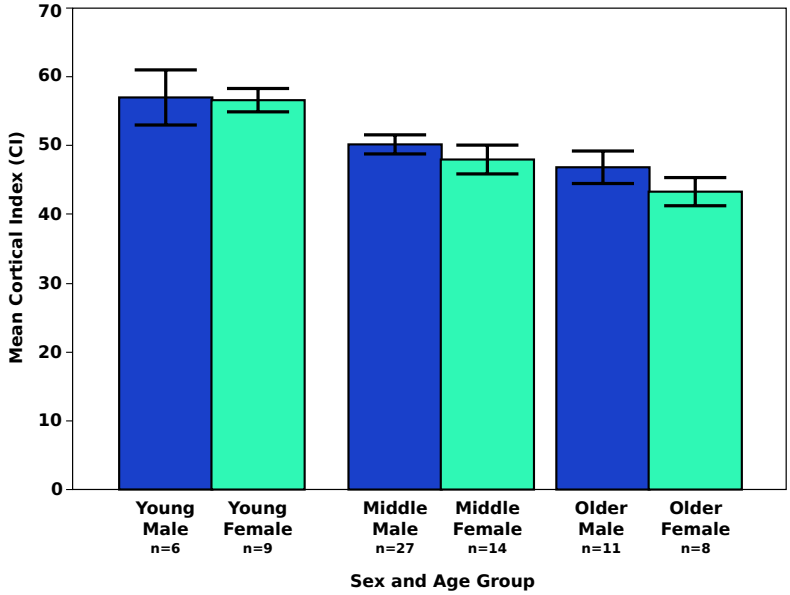

Figure 5.4: Mean cortical index (CI) values plotted for each age and sex group. Error bars are one standard error of the mean. Male means are plotted in dark blue; female means are plotted in green. Age groups are young (18-29 years), middle (30-49 years), older (50+ years). Within each age category there are no statistically significant differences between males and females. Within each sex there are statistically significant differences between age groups, with CI values declining from young to older age.

We also compared male and female same-age cohorts for all measurements. Table 5.3 (above) summarizes the statistical results (from Student's t-tests) of those comparisons. Figure 5.4 illustrates the pattern of bone loss by sex and age using the cortical index measurement. In young age, male and female CI was essentially equal. In the middle and older age groups women have lower CI values than the males but there are not statistically significant differences between

the sexes within the same age cohort. We do note that for cortical thickness (CT), there is a significant sex difference within each age group (see Figure 5.5, below). In young age, male CT is significantly larger than female CT. Both sexes have declines in CT in middle and older age, with the females always having significantly smaller CT values than their age-matched male peers. This is related to the significant sexual dimorphism that is not accounted for in CT measurements. CTI corrects for size, and when we compare CTI between males and females within each age category we see no statistically significant differences (Figure 5.5). Therefore, the CTI data suggest that there are no differences in cortical bone thickness between the sexes, instead CTI changes with age, with a pattern of continuous decline over the lifetime for both males and females.

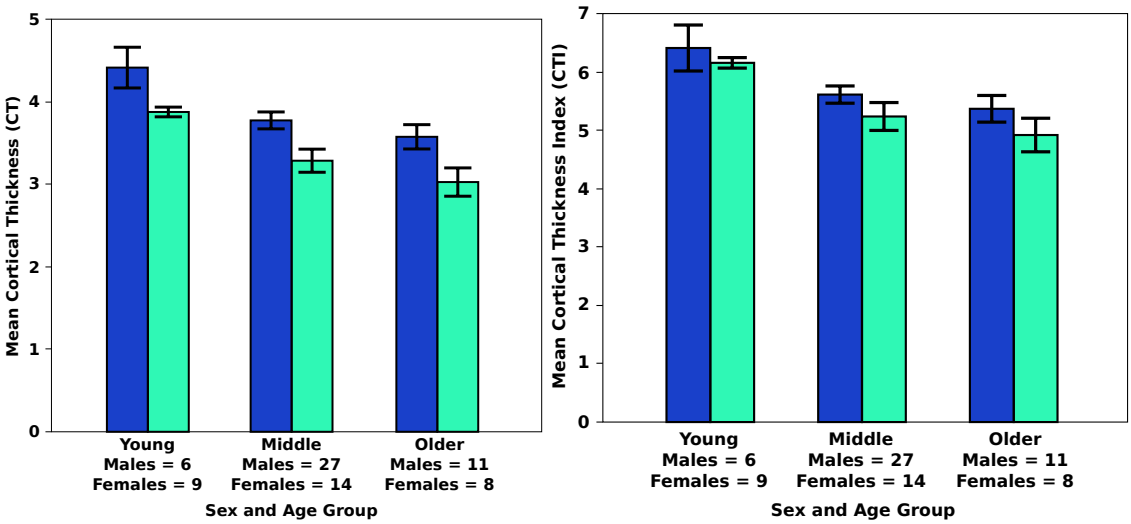

Figure 5.5: Mean cortical thickness (CT, left graph) and mean cortical thickness index (CTI, right graph) values plotted for each age and sex group. Error bars are one standard error of the mean. Male means are plotted in dark blue; female means are plotted in green. Age groups are young (18-29 years), middle (30-49 years), older (50+ years). There are statistically significant differences between males and females within each age group for CT but not for CTI. CTI shows significant declines from young to older age for both sexes.

Individuals with lower bone mass may be at greater risk for osteoporotic fracture. We assessed abnormally low bone mass levels for this population following the work of Meema and Meema (1987) and Beauchesne and Agarwal (2014). Individuals whose CI values are more than two standard deviations below the mean CI for the 18-29 year olds of their own sex are considered to have abnormally low bone mass. A 'cutoff' CI value was therefore calculated for each sex and then examined for each age group within that sex (see Table 5.4, below). For both sexes, no one in the young age category has low bone mass. For middle and older aged females, about half (40-50%) of each age cohort has abnormally low bone CI. For males, there is an increasing trend across the age groups with under 5% of the population showing abnormal CI in middle age, which increases to almost 20% for older age males.

Table 5.4: Sex- and age-related patterns of low bone mass for the Tibanica population using the standard set by Meema and Meema (1987). The 'cutoff' values are calculated as 2 standard deviations below the sex-specific mean for the 18-29 year-old cohort. Values indicate the number of individuals per age and sex group that exhibit low bone mass (CI values below the 'cutoff').

Age Group		Meema & Meema (1987)
Females		CI <2 SD of 18-29 mean (cutoff is 46.43)
18-29 years		0/9 (0%)
30 - 49 years		6/14 (43%)
50+ years		4/8 (50%)
Males		CI <2 SD of 18-29 mean (cutoff is 37.39)
18-29 years		0/6 (0%)
30 - 49 years		1/27 (4%)
50+ years		2/11 (18%)

Discussion

For the Tibanica population we see evidence of bone maintenance and loss associated with both sex and age. Similar to modern populations, peak bone mass in the metacarpal occurs in the young age group (18-29 years) for both men and women (associated with highest CI and CT, lowest MA values). No periosteal expansion is noted for Tibanica peoples with age, suggesting that adequate bone is laid down during adolescence and early adulthood which is then maintained over the lifetime. Some studies have seen periosteal expansion with age. For example, TW increased in females from Velia, Italy, with middle and older women having the greatest TW values, but this trend was not observed for the men from Velia (Beauchesne and Agarwal, 2014). Other populations have periosteal expansion over the whole lifetime for both men and women, though these increases to TW are always small and may not be statistically significant (Mays, 2000, 2001). This Muisca population does not show any changes to total width with age, indicating that maximum bone width is achieved in early adulthood and that periosteal bone surface is maintained over the lifetime. Continuous periosteal expansion is more commonly observed in males, and researchers believe increases in TW may be related to continuous stressful manual labor that encourages bone development (Mays, 2000; Böttcher et al., 2006). The lack of change in TW over the lifetime of Tibanica women and men may indicate that physically demanding labor began earlier in life (during adolescence) causing peak bone mass to be achieved in early adulthood, and then consistent levels of labor over the entire lifetime maintained the periosteal surface.

Both men and women in this population show a pattern of bone loss as they age, with significant loss by the time individuals reach older age (50+ years). Women lose more bone at an earlier age than men, beginning in their 30's and 40's. This loss is apparent through increasing medullary width (and MWI) corresponding to declining CI, CT, and CTI values with age, particularly for females. Unfortunately, we are unable to further refine the age when bone loss occurs within these broad age categories due to limitations in accurate assessment of age-at-death. The loss of bone for both females and males in old age is interesting as it indicates that endosteal bone loss for this population is tied to aging for both sexes, but that females have a(n) additional factor(s) causing some women to lose bone at an earlier age. Medullary width expansion in both sexes is likely the result of resorption of bone from the endosteal surface,

leading to thinning of the cortex. In females we see both MW and MWI increasing significantly between young and older age. For males, there is only a statistically significant difference in MWI between younger and older age (though this is *barely* significant, $p = 0.0467$).

Overall, males only show bone loss in the oldest age group, with CI, CT, and CTI declining significantly between young and old age. The fracture risk calculations based on Meema and Meema (1987) show a very low risk of fracture in young (0%) and middle aged males (4%) which increases significantly once men are over 50 years old (18% fracture risk). This pattern, where males retain more cortical bone into older age, has been observed in many modern populations, with periosteal maintenance and/or expansion outpacing endosteal bone loss until old age (Maggio et al., 1997; Böttcher et al., 2006; Szulc and Seeman, 2009). Therefore, the Tibanica males appear to follow the same trend, with bone loss only occurring in the oldest age group and only some men showing loss that may have compromised their bone health.

The pattern of bone loss for women is apparent in declining CI, CT, and CTI values across the age groups. These patterns are consistent with many studies of modern women, where bone loss is seen to steadily occur as females age, though in modern populations this decline is commonly associated with hormonal changes accompanying menopause, and therefore occurs in women in their late 40s and early 50s (Toledo and Jergas, 2005; Böttcher et al., 2006). Interestingly, the statistically significant declines in both CI and CTI are between young and middle aged women, and young and older aged women, with no significant difference between middle and older aged women. The middle-age decline in cortical bone for females may be associated with bone loss due to pregnancy and lactation (Black et al., 2000; Agarwal and Stuart-Macadam, 2003; Martin, 2003; Toledo and Jergas, 2005). Modern clinical data show conflicting evidence of the effects of pregnancy and lactation on bone maintenance and loss, with evidence for loss and gain throughout pregnancy (Kolthoff et al., 1998; Black et al., 2000; More et al., 2001). Some studies show no change in bone content during and after lactation while others show a net loss (Lamke et al., 1977; Drinkwater and Chesnut, 1991; Kent et al., 1993; Sowers and Galuska, 1993; Sowers et al., 1995; Sowers, 1996). Modern clinical data from Colombian populations suggest that pregnancy may have a protective benefit for females, lowering their risk of developing osteopenia or osteoporosis in later life (Cure-Cure et al., 2002). However, these studies of present-day Colombians reflect a very heterogeneous population that is dramatically different from pre-contact Muisca peoples. The fracture risk calculations based on Meema and Meema (1987) support the hypothesis that significant bone loss occurs starting in middle age for the Tibanica women, with their fracture risk estimated at 43%. For older age females (50+ years) fracture risk was estimated at 50%, indicating only a slight increase in risk associated with the transition to older age. It is possible that the women of Tibanica who died in middle adulthood (30s to 40s) were pregnant and/or lactating at their time of death, and that had these women lived, some may have recovered the bone they lost, while others may not have, which may explain why we see very little difference between middle and older aged women. The loss of bone in both middle and older aged females may therefore be the result of multiple factors interacting, including parity and lactation history, nutrition, activity, and overall health status. Despite bone loss, risk of fracture is still low for the people from Tibanica, as only a small number of fractures associated with metabolic bone disease were observed in a sample of the Tibanica population, particularly in the vertebrae.

Studies of other (pre)historic populations (Sudanese Nubians, medieval Danish and medieval British) have hypothesized that pregnancy and lactation played a role in the observed

bone loss for some females (Armelagos et al., 1972; Martin and Armelagos, 1979; Martin, 1981; Martin et al., 1984, 1985; Martin and Armelagos, 1985; Poulsen et al., 2001; Agarwal et al., 2004). Analysis of trabecular bone structure in the British Medieval sample from Wharram Percy indicated bone loss for women beginning in middle age (30-49 year-old age group) with little change into old age (Agarwal et al., 2004; Agarwal and Grynpas, 2009). The authors suggest that females for this population may have had bone loss at specific skeletal sites related to pregnancy and lactation mineral requirements and that despite the bone loss in specific areas of the body their overall skeletal health was not significantly compromised (Agarwal et al., 2004; Agarwal and Grynpas, 2009). However, Mays (1996) studied the second metacarpals of the same sample from Wharram Percy and did not find cortical bone loss in middle age women, instead finding a pattern of gradual loss with significant change between young and older aged females. This differs for Tibanica, where females show a loss of metacarpal cortical bone starting in middle age, but that overall cortical bone quantity is preserved between middle and older age. Therefore, similar to the findings of Agarwal et al. (2004) the lack of a major decline in bone quantity between middle and older age suggest that menopausal hormonal changes had less of an effect on bone maintenance and loss for Tibanica females. Future studies examining other bones such as the rib, vertebrae, and long bones for evidence of cortical bone maintenance and loss could provide additional information about how different skeletal sites may be responding to biological and cultural processes (for example, see Agarwal et al. (2015). Additionally, identifying age of weaning in Tibanica children through stable isotope analyses could provide evidence to determine lactation practices for Muisca women. Further study of other South American prehistoric and modern populations could aid in disentangling the effects of various biological and cultural factors in patterns of bone maintenance and loss.

When we examine Tibanica women and men within their age-cohorts we see a number of interesting patterns. As expected, TL, TW and CT are statistically significantly different between the sexes within each age group, since each of these measures is strongly tied to sexual dimorphism within this population. It is interesting then to note that for every other measure, MW, MWI, CI and CTI there are no statistically significant differences between males and females for each age group. A modern clinical study of young and middle aged men and women from Colombia using DXA indicate bone mineral density increases for men and women in the spine from their 20s to their 30s while both sexes lose bone mineral density in the femoral neck between those age groups (Jauregui Cuartas, 2014). That study indicates different changes with age between the femur and the vertebrae in young and middle aged individuals, but both sexes follow the same patterns of BMD increase or decline at the same bone sites (Jauregui Cuartas, 2014). The Tibanica data suggest that in general there is little difference between the sexes in terms of bone quantity at each age, particularly in old age where modern populations often see a dramatic difference between men and women. For example, in modern (mostly Western) populations we see differences in CI between the sexes in the older age category where postmenopausal bone loss is usually severe in women while older age males do not show a dramatic decline in CI (Maggio et al., 1997; Agarwal and Stuart-Macadam, 2003; Stini, 2003; Böttcher et al., 2006). These prehistoric data therefore suggest that the postmenopausal changes to females observed in modern populations may not have been a significant factor for the women in this prehistoric Muisca context. Indeed, other bioarchaeological studies have also noted that modern sex- and age-related patterns of bone maintenance and loss do not always apply to ancient populations (Lees et al., 1993; Mays, 1996; Agarwal and Grynpas, 2009; Glencross and Agarwal, 2011).

Table 5.5: Summary of CI data for Tibanica, Wharram Percy (Mays, 1996), Ancaster (Mays, 2006), and Velia (Beauchesne & Agarwal, 2014)

	Tibanica		Wharram Percy		Ancaster		Velia	
Age Group	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Females								
18-29 years	56.61 n=9	5.09	49.5 n=15	9.7	51.8 n=11	10.7	55.1 n=7	7.5
30-49 years	47.98 n=14	7.84	44.4 n=27	8.4	47 n=12	5.7	49.7 n=15	10
50+ years	43.31 n=8	5.79	41.5 n=23	7.9	34 n=16	6.7	38.4 n=10	6
Males								
18-29 years	57.01 n=6	9.81	42.9 n=10	7.8	N/A	N/A	53.1 n=6	9
30-49 years	50.18 n=27	7.21	45.4 n=29	9	N/A	N/A	51.2 n=20	7.4
50+ years	46.86 n=11	7.84	40.4 n=34	7.1	N/A	N/A	41.5 n=13	12.2

To date, no studies have been published examining archaeological populations using metacarpal radiogrammetry for South American populations (or any Native American prehistoric populations). Therefore, this study is limited to comparing the Tibanica data to published works with the most complete data, all of which emphasize European populations. Major limitations to this comparison include significant differences in genetics, nutrition, physical activity, and overall lifestyle. Given these caveats only observations of general patterns comparing this Muisca sample to other populations will be made. Cortical index (CI) is a standardized measure included in all metacarpal radiogrammetry studies published to date. In Tables 5.5 and 5.6 (above and below) we list the published CI data for our Tibanica sample in comparison to data from Wharram Percy (Medieval British), Ancaster (3-4th Century England), and Velia (1st-2nd Century Italy). The Tibanica individuals have CI values most similar to Velia for both men and women across the various age groups. The populations from Tibanica and Wharram Percy appear to be the most different, with Tibanica women and men having greater CI values for every age group.

Looking at the CI values between populations as a percentage of bone retained with age (based on the age at peak bone mass), we see that like the other populations, the youngest Tibanica individuals have the highest CI, therefore the baseline is the young-age group mean (note the exception for Wharram Percy males who reach peak bone mass in the middle age group). The Tibanica women decline to 85% of their original peak CI in middle age, the lowest percentage of all the comparative populations (contrasted to Ancaster and Velia which are at 90% of their original CI value for the same age). However, during older age the Tibanica women only drop to 77% of the young CI while the older women in other populations declined significantly more (66% for Ancaster, 70% for Velia), with only Wharram Percy showing the greatest preservation of CI in old age (84% of young age CI). The Tibanica men show a steady decline of CI with age, similar to the men from Velia but in old age the Tibanica men retain slightly more of their cortex (82%) than the men from Velia (78%). The men from Wharram Percy show a different pattern than the other populations, with peak bone mass achieved in the middle age group (rather than in younger age), and the males from Wharram Percy retain the most bone in older age (89% of original CI). Therefore, we see that the Tibanica population follow similar patterns of bone maintenance and loss to other archaeological populations, particularly similar to the 1st-2nd century Italian people of Velia.

Table 5.6: Comparison of mean CI values by age groups as measured by percentages of peak bone mass (assessed as age at highest mean CI) for Tibanica, Wharram Percy (Mays, 1996), Ancaster (Mays, 2006), Velia (Beauchesne & Agarwal, 2014).

	Tibanica		Wharram Percy		Ancaster		Velia	
Age Group	**Mean**	**%**	**Mean**	**%**	**Mean**	**%**	**Mean**	**%**
Females								
18-29 years	56.6 n=9	100%	49.5 n=15	100%	51.8 n=11	100%	55.1 n=7	100%
30-49 years	48.0 n=14	84.70%	44.4 n=27	89.70%	47 n=12	90.70%	49.7 n=15	90.20%
50+ years	43.3 n=8	76.50%	41.5 n=23	83.80%	34 n=16	65.60%	38.4 n=10	69.70%
Males								
18-29 years	57.0 n=6	100%	42.9 n=10	94.50%	N/A	N/A	53.1 n=6	100%
30-49 years	50.2 n=27	88.10%	45.4 n=29	100%	N/A	N/A	51.2 n=20	96.40%
50+ years	46.9 n=11	82.30%	40.4 n=34	89%	N/A	N/A	41.5 n=13	78.10%

Bone maintenance and loss are a function of many biological and cultural factors, including genetics, diet and nutrition, physical activity patterns, and overall health status. Bone health for the Tibanica community changes over the lifetime, with females particularly susceptible to bone loss possibly due to pregnancy and lactation, though additional factors likely mediate the effects of parity on bone health for women. Stable isotope analysis has revealed detailed dietary information for the Tibanica population (see Chapter 3, this dissertation). During childhood, males consumed more maize than females, but both males and females had equal access to protein sources. This suggests that childhood nutrition was likely good for both boys and girls, with sufficient protein consumption to aid in bone development. During adulthood, men and women show different dietary patterns with males consuming more maize and slightly more meat than females. As both sexes age (following the same young to older age groups used in this study), maize consumption declines slightly, possibly due to poor dental health in older age due to a lifetime of consuming meals rich in maize and other carbohydrates. Maize is a food source that is relatively low in protein, vitamins and minerals and high in carbohydrates, and was consumed both as a food and as a fermented beverage (*chicha*) in Muisca diets (Miller et al., In Press; Rojas de Perdomo, 1994; Cárdenas-Arroyo, 2002; Illera, 2012). As Mays (1996) notes, high levels of alcohol consumption are a risk factor for osteoporosis and it is likely that Tibanica peoples consumed alcohol regularly in the form of *chicha*. Therefore, less consumption of maize by females might actually be beneficial to skeletal health if the diet instead is made up of other, more nutritionally-rich foods. Tibanica males consumed significantly more maize than females over their entire lifetimes but the consumption of this food does not appear to negatively impact their bone development or maintenance (other than dental problems which are observed for both sexes). Since we do not see significant differences between male and female cortical bone measures but instead see bone loss with age for both sexes, it is unlikely that nutritional differences played a significant role in bone health for the Tibanica peoples.

Activity patterns for the Tibanica community have been studied using cross-sectional geometry measures of long bones (see Chapter 4, this dissertation). Studies of femurs and paired humerii indicate that male labor emphasizes lower body work while female activities were very

strenuous on the upper body. Males may have been engaged in more agricultural activities and walking longer distances over rugged Andean terrain (for gathering, hunting, trading, etc.). Females show robust upper arms with symmetrical use of both left and right arms, likely related to grinding/pounding activities for food preparation, lifting and carrying children, and weaving textiles. Mays (2000) noted that women from Spitalfields (historic 18^{th}-19^{th} century London) were involved in weaving activities which would have actively engaged the hands. The author suggested that if physical activity buffers against bone loss then we might expect to not see bone loss in the metacarpal with age, but the Spitalfields data indicate bone loss for older aged females (Mays, 2000). Mays (2000) points out that there was no bone loss indicated in the lower limb for the same population (Lees et al., 1993) and therefore there may be significant factors of weight-bearing and mechanical loading that affect which bones are remodeled, with frequently-loaded bones being the last to suffer the effects of metabolic bone loss (Mays, 2000). It is interesting then that the Tibanica women, who are clearly engaged in strenuous upper body labor, show loss of bone in the metacarpal in middle and older age. The humerus data suggest that female labor was intense but this was apparently not enough to safe-guard against bone loss when combined with factors such as pregnancy, lactation, and aging. Comparison of multiple skeletal elements may also implicate how bones that are very biomechanically active respond to metabolic changes versus bones with less loading (such as the rib) and future work will make intra-skeletal comparisons for this population.

Conclusions

The increasing prevalence of osteoporosis in aging populations around the world has prompted a number of bioarchaeologists to question the historical roots of this disease and to look for evidence of bone loss in different populations across human history. This study adds new data to the world-wide studies of patterns of bone health in the past, providing evidence of bone development, maintenance and loss for a pre-Columbian South American population. For this Muisca community, bone loss is strongly associated with age-related changes but females have a higher chance of bone loss earlier in life, likely due to pregnancy and lactation. In the oldest aged individuals from Tibanica there is no difference between the amount of cortical bone that men and women retained, a pattern that deviates from many modern studies where women often lose significantly more bone then men (Agarwal and Grynpas, 2009). While these Muisca men and women lost cortical bone in the metacarpal with age, their skeletal health may have been protected by sufficient nutrition and consistent, demanding physical activity. This data demonstrates the complex interactions that both age and sex have on skeletal development and maintenance over the lifetime. We hope that other scholars, particularly from the Americas, will utilize this non-invasive, low-cost method in future studies to better understand the complex interplays of skeletal health with variables such as sex, age, activity, and diet and nutrition.

Chapter 6: Conclusions

This dissertation has revealed significant differences between Muisca men and women across their lifetimes through analysis of dietary practices, physical activity patterns, and skeletal health. Studies of the Muisca have traditionally emphasized social inequality as it relates to status and rank within this hierarchical society. The results of this dissertation suggest that while status may have been an important aspect of Muisca life, social differences between the sexes played a very significant role in structuring the day-to-day lives of Muisca peoples. This study used three methods to examine 199 individuals to see how the variables of sex, age, and social status intersected with diet, activity, and skeletal health. I found significant patterns that united and separated groups within the Tibanica archaeological community. The results from stable isotope analysis, cross-sectional geometry, and metacarpal radiogrammetry suggest that divisions between the sexes were the fundamental divisions between groups within Muisca society. The focus on differences between genders, age groups, and people of varying status through the analysis of access to food and patterned practices of physical activity provides a window into the traces that daily life records in every body. These findings have significant implications for the interpretation of Muisca social structure and encourage us to re-think the traditional models of Muisca society.

Food and social identity are deeply intertwined and many cultures use food to mark particular groups as being distinct from one another. Personal eating habits are a reflection and product of the local environment, economics, politics, social identities, personal taste preferences, and more. Many cultural groups distinguish 'us' versus 'them' based on dietary practices, and then within the same community different social identities/roles may be marked by nuanced and layered food practices. For example, food practices may intersect with status, gender, age, religion/ideology, economic power, etc. Often we see consumption of 'luxury' foods as an identifier of social status while other groups may be marked by foods that cannot be consumed (such as taboo foods). When large-scale patterns are observed in diets across particular groups then we can infer that aspects of these identities were created and maintained through the basic act of eating. For this Muisca community we see a number of patterns emerge from the isotopic data that indicate multiple identities intersected and were expressed and embodied through food practices.

Based on previous archaeological research, I hypothesized that social status would confer dietary privilege to individuals buried with grave goods. However, we saw that for most people buried with grave goods, thought to indicate higher status, their diets were not significantly different from the rest of the Tibanica community. In general, people of high status were consuming the same range of foods as everyone else, generally eating the same kinds of ingredients. However, the individuals with the very highest nitrogen values, indicating greater meat consumption, were almost all people who were buried with grave goods. Therefore, for a very small number of people higher status was marked by greater meat consumption in life, and burial with grave goods in death. It is likely that many higher status individuals occasionally consumed different/special foods that others didn't have access to, or greater proportions of foods that were common in Muisca diets, but they didn't consume these consistently enough to have an effect on the isotopic signatures recorded in their skeleton. These findings were unexpected given the significant attention that social status has been afforded in discussions of ancient Muisca society and the underlying assumption that higher status would confer greater access to coveted resources such as food.

I also proposed the hypothesis that Tibanica males would have greater access to meat and maize (based on patterns observed in other Andean and Mesoamerican communities). The isotopic results do indicate some differential access to certain resources, with maize and meats being two food groups that men had greater access to, while women also consumed these same resources but less frequently or in less quantity. Additionally, this study used a lifecourse approach, which charted dietary change and stability for these individuals as they went from girls and boys to men and women. I found that beginning in childhood, boys were already being fed greater amounts of maize than girls, suggesting that maize and male-gender identity were intertwined. Tibanica boys were being socialized into male identities starting during childhood and food practices were part of the process of becoming a Tibanica man. Girls were also being socialized with food through their eating habits which relied on greater proportions of tubers, beans, squash/gourds, fruits and other C_3-type foods, girls were creating and maintaining their own feminine identities. Through isotope analysis of multiple skeletal tissues, I demonstrated that a person's sex is deeply tied to eating practices and these behaviors create and reify masculine and feminine identities across the lifetime.

Some age-related dietary changes were noted for the Tibanica population. During childhood both girls and boys had similar levels of protein consumption, but during adulthood, many men had greater access to proteinaceous foods compared to adult women. Males show a relatively high level of maize consumption over the entire lifetime, with only a slight decrease corresponding to older age. Females also show a pattern of decreasing maize consumption across adulthood. I suggested that this decline in maize consumption during older age (50+ years of age) is related to poor dental health including dental caries and antemortem tooth loss. It is possible that decades of consuming maize caused poor dental health and that by the time a person was older they no longer had the necessary healthy dental structures to process (masticate) meals composed of maize. Additionally, while we see a decline in maize consumption during older age the isotopic data indicate that maize is still an important part of the diet (present, but in less quantity), suggesting that maize meals may have switched to gruel/porridge, which requires less chewing, as well as continuing fermented maize beer (*chicha*) consumption, requiring no chewing, in old age. Older aged people may no longer have the dental apparatus to consume as much maize as they did earlier in life, causing a change to the way they consume this important crop.

This project also revealed that for Tibanica peoples, physical activities (daily labor/work/chores) were strongly divided by sex. I hypothesized that males would have stronger femurs and humerii than females and also that both sexes would show bilateral asymmetry in the upper arms due to hand-dominance in daily tasks. Cross-sectional geometry of femurs and humerus bones indicated that male labor emphasized the lower body while female labor was concentrated on the upper body. The femur bones of Tibanica men were larger, stronger, and more robust than the femurs of Tibanica women. Male femurs also maintained their greater strength over the entire lifetime, with the oldest males having very robust legs. In contrast, the Tibanica women had incredibly robust upper arms, with their standardized bone measures indicating humeral strength was greater in females than it was for males. Females also show consistently high levels of strenuous work in the upper body work across the entire lifetime; their robusticity and strength measures do not decrease with age. The humerii data also indicated that women's work used both hands as all females showed low levels bilateral asymmetry, while male tasks were right-hand dominated. Therefore, neither of my hypotheses were supported by the data.

From the cross-sectional geometry data, a clear pattern of gendered division of labor emerges. Males may have conducted a greater amount of agricultural work than females and use of digging sticks for agricultural work may have reinforced the continuous stress on men's legs (Rojas de Perdomo, 1994). Males may have also been walking greater distances over the Andean terrain, possibly for gathering, hunting, mining, or trading (Langebaek Rueda, 1987; Rojas de Perdomo, 1994; Illera, 2012; Cardale Schrimpff, 2015). These activities would have emphasized lower body development and continuity of these activities over men's entire lives would have maintained their robust leg features. Males also show higher levels of bilateral asymmetry in the humerus and indicate that the majority of men were right-hand dominant. Many of the activities humans perform in daily life are carried out by the dominant arm and hand, and it is possible that men were actively hunting, gathering, building and crafting products with an emphasis on right-handed motor skills. In contrast to this we see Tibanica women working intensively with their upper bodies and showing extremely low levels of bilateral asymmetry, suggesting both arms were actively engaged in most activity tasks. The upper arms of women were significantly larger than men's for every strength and robusticity measure, an incredibly unusual and important discovery that has rarely been noted in other ancient populations studied to date (Wescott and Cunningham, 2006; Ogilvie and Hilton, 2011). Tibanica women were using both arms for very strenuous labor, likely related to food processing and preparation, industries like weaving, and caring for children. The preparation of crops like maize and yuca often involve grinding and pounding, activities that typically used grinding stones and require significant upper body strength (and bilateral strength). These activities were intense and continuous over their lifetimes, even into older age, indicating that these practices were deeply intertwined with women's daily lives.

When we examine the dietary data in conjunction with the activity data we can see how male and female spheres were sharply delineated but also overlap. The dietary data demonstrate that maize was a very important food for all Muisca peoples, but males in particular had greater access to this food over their lifetimes. Historical sources noted that the Muisca consumed a variety of foods, but one that was particularly noted was the alcoholic drink known as *chicha*, commonly made from fermented maize (Llano Restrepo and Campuzano Cifuentes, 1994; Rojas de Perdomo, 1994; Langebaek, 2005; Illera, 2012). Numerous other Andean polities incorporated *chicha* consumption into their social systems, with imbibing often linked to social, political, economic, and religious events (Morris, 1979; Hastorf and Johannessen, 1993; Bray, 2003a). The finding that Tibanica males consumed more maize than females follows a pattern that has been noted for some other Andean communities (Hastorf, 1991; Somerville et al., 2015). It is interesting then that we see a pattern where women actively prepared the maize, grinding it for food and drinks, and that males then consumed those maize-based products in greater quantities than the females who created them. It is possible that women were in charge of preparing *chicha* and it is likely that they also consumed this beverage but not in the same quantity or frequency that males did. I also noted that many males had greater protein consumption than females did, and that much of this protein was likely from birds, aquatic species, or animals that consumed C_4 plants. The Tibanica males may have been traversing more of their Andean territory, and during these activities and outings consumed animals that were hunted/trapped/fished or traded. Historical records indicate that salt mines within Muisca territory were an important economic source for people to utilize in trading both within their own economy and with neighboring groups (Rojas de Perdomo, 1994; Illera, 2012; Cardale Schrimpff, 2015). It is also noted that neighboring groups would salt-cure freshwater fish,

something the Muisca may have also done for food preservation, or salt-cured fish may have been a product the Muisca traded for. If males were the primary individuals engaged in trading activities, they would have had greater access to non-local food items. By bringing these two data sets into a dialogue we have a clearer picture of Muisca lifestyles, with spheres of activity and consumption that actively separated women and men in some of their daily practices.

It is important to also reflect on these practices from embodiment and lifecourse perspectives: these spheres, where diet and activity become embodied cultural expressions, are initially foisted upon children without choice, but through time become part of daily life and are continued by each person over her/his life, processes and practices that are inextricable from one's identities. For example, childhood diets reveal the practices that parents, relatives and kin impose on children through feeding them particular meals, and over time these practices become naturalized so that these actions are non-discursive (though that doesn't mean they are not flexible or cannot be changed), and importantly they become reified through the personal adoption of these practices by each community member as s/he ages. In this way we see how something as common and quotidian as eating becomes a social act that creates and maintains the social person, with the human body literally composed and marked (through chemical traces from dietary sources, through repeated strain on arms and legs building bone) as a member of particular social groups through the act of consuming food. The patterned division of labor between men and women suggest that daily activities were intricately linked to one's sex, marking the economic and socio-political spheres between men and women through different skill sets. Therefore, a Muisca child would see these activities modeled by adults and over time learn the skill sets that were aligned with their particular social groupings (likely a series of intersecting identities with sex as a primary division but additional variables of age, status, ability, etc. contributing to a person's labor and chores). These practices reveal how socialization and identity formation and maintenance are predicated on participatory actions that reinforce cultural norms. Following the work of Joyce (2000, 2005) we can see that diet and labor practices were actions that socialized individuals through their participation ("boying the boy and girling the girl" (Joyce, 2000) and that these behaviors began during childhood as an external force acting on the person who then internalized and normalized these ways of being so as to maintain them across a lifetime, and across generations. It is in these moments of ordinary activity that socio-cultural effects on individuals can be seen so clearly (some scholars, such as Judith Butler (1993), have described this as the insidious way that culture operates both on us and within us), and how naturalized these ways of being are for each of us, both ancient and modern people alike. We see how these simple acts, like eating and working, are taken for granted as naturalized ways of being, but in fact these are fundamental aspects of social identity construction and maintenance, and allow us to continue to maneuver within our specific social milieu.

For the majority of individuals from Tibanica there are clear gender divisions that they embodied in their daily life, but some individuals appear to have transgressed the traditional trajectories. These interesting individuals often appear as "outliers" when compared to their own sex, age, and status cohorts, and these unique individuals may represent people who did not conform to traditional Muisca norms for their social groupings, perhaps representing other (non-binary genders) or occupying a social space that was non-normative but socially coherent to other Muisca peoples. Currently we can only speculate on the lives of these people and the social space they occupied, but future studies of these individuals who do not conform to the general

patterns observed for diet and activity may reveal additional significant information about Muisca life.

Finally, the skeletal health data indicate that both women and men from Tibanica lost cortical bone in the hand in older age. Changes to bone quantity appeared to impact women more severely than men, and earlier in life, possibly due to skeletal responses to pregnancy and/or lactation. While bone loss occurred for both sexes with age (particularly in the individuals over 50 years old), overall skeletal health may not have been compromised. Cross-sectional geometry analysis of long bones such as the femur and humerus indicated that for many people appositional bone growth continued as people aged while endosteal resorption also occurred with age. Since bone diameter continued to increase over time the structural properties of the bone were not likely to be compromised even if there was some net bone loss (strength is retained due to distribution of force over a greater cross-sectional area). A preliminary study of skeletal trauma within this sample did not find many fractures typically associated with skeletal fragility (femur, radius, ulna), however a small number of individuals did have fractures in their vertebrae, possibly linked to age-related bone loss (for example see Agarwal et al., 2004). Future work will compare bone maintenance and loss at the different skeletal sites for the same individuals (metacarpal, femur, humerus) and will include study of cortical bone in the rib. Additionally, I will continue to examine Tibanica individuals for evidence of fracture and trauma related both to compromised health and possibly inter-personal violence.

Complex social relationships for this Muisca community have been revealed through the study of human diet and activity patterns. Upon beginning this project, I did not anticipate discovering the dramatic gender divisions that were ultimately uncovered. The previous research on the Muisca peoples has been deeply influenced by the historical documents recorded during the 16th and 17th centuries, coloring many interpretations of Muisca prehistory and limiting the discussion of Muisca socio-political and economic structures within these projected frameworks. By attending to variables such as sex and age in addition to the more traditional variable of social status, this project has implicated new and intersecting areas of social inequality that have not been examined for the Muisca. The domains of study for this project emphasize the common experience of individuals, as eating and working are two of the most basic human activities that structure daily life. The revelation that these two basic spheres of experience are demarcated along the lines of sex, and often have layered interactions with age and social status, suggest that one of the most important and fundamental divisions within Muisca society was between the sexes. While this is not necessarily a surprising finding (many other cultures across time and space have demonstrated that sex-differences were a primary driver of social differentiation), this avenue of social difference and its subsequent effects on social organization has not been explored for the Muisca and deserves greater recognition. This dissertation has shown that both men and women have access to diets sufficient to form healthy bodies, and that both sexes work hard all of their lives, just doing different kinds of work. Therefore, on some of the major sources of inequality, we actually see men and women are equal but different. These differences may be evidence of parallelism/duality between the sexes, with complementary roles of men and women that demonstrate difference through action and practice, but do not necessarily indicate inequality. Duality (in many forms, not just limited to female-male spheres) is a characteristic that has been noted in many Andean societies, and the Muisca may therefore demonstrate another expression of this cultural phenomenon. (Murra, 1968; Harris, 1978, 1980; Klein, 1993; Gelles, 1995; Moore, 1995; Isbell, 1997; Jenkins, 2001; Allen, 2002; Urton, 2003; Arkush and Stanish, 2005; Beaule, 2016). If the sexes were seen as complementary but different in Muisca

culture, then social inequality and other kinds of social difference may emerge at the intersection of other identities and social roles, with layers of social meaning transforming social relationships and social structures.

This dissertation has shown how bioarchaeological methods can make social inequality and its diversity visible in ancient people through the study of social identities and relationships that are materialized in the daily activities that constrain what one can eat and do with their body. Many new questions emerge from these research findings, such as: when did gendered divisions of eating and working becoming part of Muisca culture and do these change through time and space? Are the findings reported here unique to Tibanica or are these shared cultural practices that can be observed in other Muisca communities? Did Muisca men and women share and live in the same spaces on a daily basis or are there separate spheres of activity/habitation that reinforce these gender divisions? Did they eat together? The division of labor along lines of sex are quite marked: do we see activity spaces that support or provide other lines of evidence to think about how men and women's work structured their life and shaped their communities (both through action and in literal landscape/constructed spaces)? Since diet and activity were strongly marked by gender, was food preparation limited to one gender or did both males and females participate in food production and meal cooking? The data generated by this dissertation suggest that a reevaluation of previously studied Muisca archaeological sites and materials may provide new information about Muisca history and nuance our understanding of this unique Andean culture. Hopefully the questions I have posed here will be advanced through further study of Muisca archaeology and documentary history, particularly with a keen eye towards evidence of social inequality and social difference not only related to social status but also in conjunction with sex, age, and other meaningful biosocial identities. Such data of embodied difference expand our view of the past and the present in a complex, nuanced manner and provide an opportunity to understand people and cultures in transition today through the experiences of those in the past.

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Appendix A: Modern Colombian plant samples analyzed for stable isotope data. Plants were collected from a farm in Tequendama, Colombia in 2015. Carbon isotope data has not been adjusted to account for the Suess effect. Samples that were analyzed in replicate and averaged are indicated by a star (*) in the plant part sampled column

Sample Name	Plant Part Sampled	Spanish Name	Common English Name	% N	% C	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)
Acca oppositifolia	leaf			4.3	36.2	4.7	-27.4
Acca sellouriana	fruit*			0.6	38.2	5.9	-21.9
Aloysia citriodora	leaf		Lemon Verbena	4.1	39.5	8.2	-25.0
Capsicum (variety: chicheperro)	fruit	Ají Chicheperro	Chile pepper	2.8	47.3	4.3	-29.4
Capsicum (note: ripe fruit, red)	fruit	Ají	Chile pepper	1.2	42.3	7.2	-26.9
Capsicum (note: fruit green)	fruit	Ají	Chile pepper	1.2	42.1	5.7	-27.5
Chenopodium ambrosiodes	leaf		Paico	4.7	37.3	9.0	-27.8
Crescentia cujete	starch			1.0	39.9	3.4	-24.7
Cucurbita ficifolia	skin	Calabaza	Squash/Gourd	2.1	41.4	-1.9	-22.2
Cucurbita ficifolia	starch			1.8	40.6	-1.7	-20.9
Cucurbita ficifolia	Average of skin & starch			2.0	41.0	-1.8	-21.5
Cucurbita maxima	starch	Ahuyama	Squash/Gourd	1.6	40.2	6.2	-26.1
Cucurbita maxima	skin			2.9	42.0	5.6	-27.5
Cucurbita maxima	Average of skin & starch			2.2	41.1	5.9	-26.8
Gallinsoga parviflora	leaf	Guasca		3.4	35.1	11.6	-29.6

Impomea batatas	skin		Sweet potato	1.7	44.2	3.8	-29.2
Impomea batatas	starch			0.6	37.8	3.5	-28.6
Impomea batatas	Average of skin & starch			1.2	41.0	3.7	-28.9
Juglans neotropica	seeds		Andean walnut	4.4	63.3	10.3	-27.0
Manihot	skin	Yuca	Yuca	2.0	43.8	3.4	-27.5
Manihot	starch*			0.5	39.1	3.3	-24.8
Manihot	average of skin & starch			1.3	41.4	3.3	-26.2
Raponea lorentziana	leaf	Guarani?		2.2	42.0	8.0	-26.9
Sechium edule	skin		Chayote fruit	5.3	39.7	1.7	-26.7
Sechium edule	starch			3.7	38.5	0.9	-24.5
Sechium edule	average of skin & starch			4.5	39.1	1.3	-25.6
Solanum betacum	fruit*	Tomate de arbol		1.2	38.3	10.2	-25.6
Solanum quitoense	pulp & seeds	Lulo	Lulo	3.5	48.8	8.4	-25.2
Solanum quitoense	skin			1.4	51.6	8.5	-27.9
Solanum quitoense	average of pulp, seeds, skin			2.4	50.2	8.5	-26.5
Solanum tuberosum pastusa	flower	Papa	Potato	4.1	43.7	6.6	-24.0
Solanum tuberosum pastusa	skin			4.4	35.6	10.5	-23.2

Solanum tuberosum pastusa	starch			1.4	35.2	9.9	-21.7
Solanum tuberosum pastusa	whole tuber (skin and starch)*			2.6	37.6	10.2	-21.8
Solanum tuberosum sabanaera	skin	Papa	Potato	3.9	43.0	13.0	-25.5
Solanum tuberosum sabanaera	starch			0.9	39.4	11.5	-25.4
Solanum tuberosum sabanera	whole tuber (skin and starch)*			1.8	37.7	12.3	-25.4
Tropaeolum tuberosum cubio (note: sample 1)	skin	Cubio		2.8	38.3	3.2	-28.7
Tropaeolum tuberosum cubio (note: sample 1)	starch			2.5	37.6	3.2	-28.1
Tropaeolum tuberosum cubio (note: sample 1)	whole tuber (skin and starch)			2.2	39.5	2.8	-28.4
Tropaeolum tuberosum cubio (note: sample 2)	skin	Cubio		3.7	39.1	3.4	-23.8
Tropaeolum tuberosum cubio (note: sample 2)	starch			2.5	39.3	2.9	-23.3
Tropaeolum tuberosum cubio (note: sample 2)	whole tuber (skin and starch)*			2.7	39.3	3.1	-23.3
Ullucus tuberosus (note: sample 1)	skin	Chugua		2.6	41.8	2.8	-22.9
Ullucus tuberosus (note: sample 1)	starch			2.2	38.7	2.9	-22.4
Ullucus tuberosus (note: sample 1)	whole tuber (skin and starch)			2.3	35.8	2.8	-22.6
Ullucus tuberosus (note: sample 2)	skin	Chugua		2.9	43.3	1.3	-27.2
Ullucus tuberosus (note: sample 2)	starch			2.2	35.9	1.7	-25.9
Ullucus tuberosus (note: sample 2)	whole tuber (skin and starch)*			2.1	37.5	1.9	-25.7

Vasconcella pubescens	fruit	Papayuela		2.5	40.7	9.1	-26.2
Xanthosoma sagittifolium	skin		Arrowleaf/Elephant ear	1.2	40.6	3.7	-25.4
Xanthosoma sagittifolium	starch			0.6	39.7	5.0	-23.7
Zea mays (note: sample 1)	seeds*	maíz	Corn	2.4	40.5	8.3	-12.3
Zea mays (note: sample 2)	seeds	maíz	Corn	2.1	37.5	8.2	-12.1

Appendix B: All Tibanica bone stable isotope data (adulthood diet)

SAMPLE ID	BURIAL GROUP	SEX	Age Group	Grave Goods	C/N bone collagen	$\delta^{13}C$ (‰) Bone Collagen	$\delta^{15}N$ (‰) Bone Collagen	$\delta^{13}C$ (‰) Bone Apatite	$\Delta\delta^{13}C$ (‰) Bone Apatite - Bone Collagen	$\delta^{13}C$ (‰) Protein prediction	$\delta^{18}O$ (‰) Bone Apatite
50	2	Female	Older (50 + years)	No	3.4	-11.2	8.7	-6.4	4.8	-16.2	-8
52	2	Male	Young (18 - 29 years)	No	3.4	-11.3	9.6	-5.9	5.4	-16.6	-8.1
104	2	Ambiguous or Indeterminate	Middle (30 - 49 years)	Yes	3.5	-11.7	9.8	-6.1	5.6	-17.1	-10.2
105	2	Female	Middle (30 - 49 years)	No	3.3	-11.3	9.2				
114	2	Female	Older (50 + years)	No	3.3	-13.3	9.6	-7.2	6.1	-18.6	-7.7
117	2	Male	Older (50 + years)	No	3.5	-12.3	9.8	-6.7	5.6	-17.5	-7.5
118	2	Female	Young (18 - 29 years)	No	3.2	-12.7	8.5	-6.4	6.3	-18.3	-8.3
161	2	Male	Middle (30 - 49 years)	No							
168	2	Female	Older (50 + years)	No	3.4	-12.7	9.4	-6.7	6	-18.1	-7.8
177	2	Male	Young (18 - 29 years)	No	3.3	-10.5	10.4	-6.1	4.4	-15.4	-8.2
192	2	Male	Middle (30 - 49 years)	No	3.4	-12.8	10.1	-7.1	5.7	-18.0	-4.5
195	2	Female	Middle (30 - 49 years)	Yes	3.4	-12.5	9.6				
198	2	Female	Middle (30 - 49 years)	No	3.4	-12.7	10.1				
245	0	Female	Middle (30 - 49 years)	Yes	3.1	-13.4	10.1				
802	0	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	3.5	-13.2	9.9	-6.6	6.6	-18.8	-6.7
811	1	Male	Young (18 - 29 years)	Yes	3.5	-12.2	10.2	-6.2	6	-17.7	-8.4
812	1	Ambiguous or Indeterminate	Young (18 - 29 years)	No	3.4	-12.9	9	-6.7	6.2	-18.4	-3.2
813	1	Female	Middle (30 - 49 years)	Yes	3.2	-13.3	9				
822	1	Male	Middle (30 - 49 years)	No	3.3	-11.1	9.3	-6.4	4.7	-16.1	-9.3
823	1	Male	Older (50 + years)	Yes	3.6	-11.8	11.1				
825	1	Ambiguous or Indeterminate	Young (18 - 29 years)	No				-7.1			-7.1
832	1	Male	Older (50 + years)	No	3.2	-11.3	8.9	-6.3	5	-16.4	-8.3
833	1	Male	Middle (30 - 49 years)	No	3.7	-11.4	9.8	-6.8	4.6	-16.3	-8.2
838	1	Male	Older (50 + years)	No	3.2	-14.1	9.5	-6.4	7.7	-20.2	0.4
839	1	Ambiguous or Indeterminate	Older (50 + years)	No	3.2	-12.4	9				
841	1	Ambiguous or Indeterminate	Middle (30 - 49 years)	Yes	3.5	-11.2	10				
847	1	Female	Young (18 - 29 years)	No	3.5	-11.5	8.7	-6.2	5.3	-16.7	-7.1

851	1	Male	Middle (30 - 49 years)	No				-7.4			-7.6
902	1	Male	Middle (30 - 49 years)	No	3.4	-12.8	9.9	-8.1	4.7	-17.4	-8.8
903	1	Female	Young (18 - 29 years)	No	3.6	-10.7	8.4	-6.1	4.6	-15.7	-7.9
924	1	Female	Older (50 + years)	Yes	3.2	-14.1	9.5				
944	1	Male	Middle (30 - 49 years)	No							
947	1	Male	Older (50 + years)	No	3.6	-13	9.5				
1021	1	Male	Middle (30 - 49 years)	Yes	3.2	-9.9	8.8	-5.8	4.1	-14.8	-8.4
1024	1	Female	Middle (30 - 49 years)	No	3.3	-12.3	9.1	-7.2	5.1	-17.3	-11
1026	1	Male	Middle (30 - 49 years)	Yes							
1027	1	Female	Middle (30 - 49 years)	No	3.2	-11.2	9.1				
1050	1	Male	Middle (30 - 49 years)	No	3.4	-12	10				
1054	1	Male	Middle (30 - 49 years)	Yes	3.3	-8.9	10.2	-5	3.9	-13.9	-10
1057	1	Ambiguous or Indeterminate	Middle (30 - 49 years)	No				-7.3			-5.6
1058	1	Ambiguous or Indeterminate	Young (18 - 29 years)	No							
1061	1	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	3.3	-11.6	8.8	-6.8	4.8	-16.5	-8
1063	1	Female	Middle (30 - 49 years)	No	3.4	-12.4	8.1	-6.9	5.5	-17.6	-8
1065	1	Male	Middle (30 - 49 years)	No				-6.6			-7.2
1067	1	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	3.5	-10.9	9.6	-5.6	5.3	-16.3	-9
1069	1	Male	Young (18 - 29 years)	No	3.5	-11.2	7.9	-6.1	5.1	-16.4	-9.4
1153	2	Female	Older (50 + years)	No	3.3	-14	9.1				
1154	2	Female	Middle (30 - 49 years)	No				-5.6			-7.7
1155	2	Female	Young (18 - 29 years)	Yes	3.2	-12.7	8.9	-6.3	6.4	-18.3	-7.5
1156	2	Male	Middle (30 - 49 years)	Yes	3.4	-11.5	10.2	-7	4.5	-16.3	-8.3
1157	2	Female	Young (18 - 29 years)	Yes	3.2	-10	9.1	-5.6	4.4	-15.1	-8.1
1159	2	Female	Middle (30 - 49 years)	No							
1163	2	Male	Middle (30 - 49 years)	No	3.2	-12.3	9.7	-7.3	5	-17.2	-8.4
1164	2	Female	Middle (30 - 49 years)	No	3.4	-13	9.5	-6.7	6.3	-18.5	-6.3
1166	2	Male	Middle (30 - 49 years)	No	3.2	-11.3	9.7				
1173	2	Male	Middle (30 - 49 years)	No	3.3	-11	9.5	-7.1	3.9	-15.5	-7.6
1174	2	Male	Middle (30 - 49 years)	No	3.3	-11.7	9.7	-6.4	5.3	-16.9	-7.3
1175	2	Female	Young (18 - 29 years)	No	3.2	-11.8	8.7				
1176	2	Female	Middle (30 - 49 years)	No	3.2	-12.8	9.5	-7.1	5.7	-18.0	-7.2
1177	2	Male	Older (50 + years)	No	3.4	-11.1	10.2	-6.1	5	-16.3	-7.8
1179	2	Male	Middle (30 - 49 years)	No	3.5	-10.2	10.1	-5.6	4.6	-15.3	-7.1
1185	2	Female	Middle (30 - 49 years)	No	3.2	-10.8	8.9				
1186	2	Female	Young (18 - 29 years)	Yes	3.6	-12.7	10.1	-7.4	5.3	-17.7	-8.7

1187	2	Female	Middle (30 - 49 years)	No	3.6	-12.2	9.7				
1188	2	Female	Middle (30 - 49 years)	Yes							
1191	2	Female	Middle (30 - 49 years)	No	3.2	-13.4	8.4	-7.3	6.1	-18.7	-6.8
1194	2	Female	Young (18 - 29 years)	No							
1196	2	Ambiguous or Indeterminate	Middle (30 - 49 years)	No				-6			-9.2
1197	2	Male	Middle (30 - 49 years)	No				-7.3			-8.6
1198	2	Female	Middle (30 - 49 years)	No	3.4	-12.4	8.4	-7.7	4.7	-17.1	-8
1210	1	Ambiguous or Indeterminate	Middle (30 - 49 years)	No				-7.5			-9.8
1211	1	Female	Middle (30 - 49 years)	No	3.5	-12.8	9.2	-7.4	5.4	-17.8	-8.5
1222	1	Female	Older (50 + years)	No	3.4	-13.8	9.3	-7.8	6	-18.9	-8.2
1230	1	Female	Older (50 + years)	No	3.5	-15.1	8.8	-9.5	5.6	-19.7	-9.1
1231	1	Female	Older (50 + years)	No	3.5	-13.6	9.4	-7.1	6.5	-19.1	-8
1233	1	Male	Older (50 + years)	Yes	3.5	-12.2	10.3	-7.3	4.9	-17.1	-8.5
1846	3	Male	Middle (30 - 49 years)	No				-6.3			-9
1865	3	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	3.6	-11.9	9.6	-5.9	6	-17.5	-5.3
1874	3	Female	Middle (30 - 49 years)	No				-6.8			-6.7
2142	3	Female	Middle (30 - 49 years)	No	3.6	-12	10.7	-6.7	5.3	-17.1	-8.4
2143	3	Female	Older (50 + years)	No	3.4	-12.5	8.6				
2208	3	Male	Middle (30 - 49 years)	No	3.4	-12.1	10.5				
2808	0	Female	Young (18 - 29 years)	No	3.3	-12.2	9.4				
2809	0	Male	Middle (30 - 49 years)	No	3.7	-10.7	10.1	-5.7	5	-15.9	-7.4
2837	3	Male	Middle (30 - 49 years)	No	3.3	-10.9	8.7				
2847	3	Male	Older (50 + years)	No	3.3	-12.2	8.4	-6.5	5.7	-17.5	-7.9
2849	3	Male	Middle (30 - 49 years)	No	3.4	-10.9	10.1	-6	4.9	-16.0	-7.6
2850	3	Female	Middle (30 - 49 years)	Yes	3.3	-10.7	9.9	-6.1	4.6	-15.7	-7.8
2857	3	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	3.3	-14.2	8.7				
2859	3	Male	Middle (30 - 49 years)	Yes				-6.1			-9.8
2863	3	Male	Middle (30 - 49 years)	No	3.2	-10.8	9.3	-5.9	4.9	-16.0	-6.5
2865	3	Female	Middle (30 - 49 years)	No	3.2	-11.1	9.4	-6.8	4.3	-15.9	-8.1
2869	3	Male	Middle (30 - 49 years)	No				-5.6			-8.6
2871	3	Ambiguous or Indeterminate	Middle (30 - 49 years)	Yes	3.6	-11	9.9				
2873	3	Female	Middle (30 - 49 years)	No	3.5	-13.3	9.9	-7.3	6	-18.6	-7
2874	3	Ambiguous or Indeterminate	Young (18 - 29 years)	No	3.5	-12.4	9.7	-6.7	5.7	-17.7	-7.6
2876	3	Male	Middle (30 - 49 years)	No	3.3	-12	9.4	-7.3	4.7	-16.8	-8.2

2878	3	Female	Older (50 + years)	No	3.6	-14.9	10.5	-9.1	5.8	-19.7	-7.2
2881	3	Female	Older (50 + years)	No	3.3	-11.5	8.7	-5.9	5.6	-16.9	-8.5
2885	3	Male	Middle (30 - 49 years)	No	3.3	-10.8	9.7				
2886	3	Ambiguous or Indeterminate	Young (18 - 29 years)	Yes	3.5	-13.1	11	-7.5	5.6	-18.2	-9.1
2887	3	Female	Middle (30 - 49 years)	No	3.3	-13.1	10.2	-7.2	5.9	-18.3	-9.2
2888	3	Male	Middle (30 - 49 years)	Yes	3.5	-11.4	9.9	-6.3	5.1	-16.6	-7.7
2891	3	Male	Young (18 - 29 years)	Yes	3.6	-11.1	9	-6.5	4.6	-16.0	-6.1
2892	3	Female	Middle (30 - 49 years)	No	3.6	-13.1	9.4				
2896	3	Ambiguous or Indeterminate	Young (18 - 29 years)	Yes				-6.7			-7.2
2897	3	Male	Middle (30 - 49 years)	Yes	3.5	-10.8	9.9	-5.5	5.3	-16.2	-8.9
2933	3	Ambiguous or Indeterminate	Older (50 + years)	No				-6.9			-8.2
2934	3	Male	Middle (30 - 49 years)	No	3.4	-13.4	9.8				
2935	3	Male	Middle (30 - 49 years)	No	3.2	-11.1	8.7	-5.4	5.7	-16.7	-7.9
2936	3	Female	Middle (30 - 49 years)	No	3.5	-12.7	9.7				
3020	1	Male	Middle (30 - 49 years)	Yes	3.6	-9.7	10.4	-4.9	4.8	-15.1	-9.2
3100	3	Male	Middle (30 - 49 years)	No	3.4	-10.7	9.5	-5.6	5.1	-16.0	-8.6
3102	3	Female	Middle (30 - 49 years)	Yes	3.2	-13.2	9.7	-6.6	6.6	-18.8	-6.9
3103	3	Male	Older (50 + years)	No	3.5	-12	10.2	-7.5	4.5	-16.7	-8.4
3106	3	Male	Middle (30 - 49 years)	No	3.4	-12	9.8	-6.5	5.5	-17.3	-9.3
3108	3	Female	Young (18 - 29 years)	No	3.4	-12	10	-7.5	4.5	-16.7	-6.6
3111	3	Female	Middle (30 - 49 years)	No	3.5	-13	9.2				
3112	3	Male	Middle (30 - 49 years)	Yes				-5.1			-8.7
3117	3	Male	Middle (30 - 49 years)	Yes				-5.8			-8.5
3118	3	Male	Older (50 + years)	No	3.5	-12.6	9.4	-6.2	6.4	-18.2	-8
3119	0	Male	Young (18 - 29 years)	No	3.5	-11.3	9.6	-6.4	4.9	-16.4	-8.2
3124	3	Female	Middle (30 - 49 years)	No	3.3	-14	9.2				
3126	3	Ambiguous or Indeterminate	Middle (30 - 49 years)	No				-7.5			-8.6
3127	3	Male	Middle (30 - 49 years)	No	3.5	-11.5	9.5				
3128	3	Male	Middle (30 - 49 years)	No	3.6	-10.8	9.9	-6.7	4.1	-15.5	-8.4
3129	3	Male	Older (50 + years)	No	3.2	-11.5	9.4	-6.5	5	-16.6	-8.9
3130	3	Female	Young (18 - 29 years)	No	3.6	-11.1	9.1	-6.3	4.8	-16.1	-7.4
3133	3	Male	Middle (30 - 49 years)	No	3.2	-11.3	10	-7	4.3	-16.0	-9.4
3134	3	Male	Middle (30 - 49 years)	No	3.1	-10.5	10				
3135	3	Male	Young (18 - 29 years)	No	3.2	-9.8	9.8	-5.6	4.2	-14.8	-8.6
3136	3	Female	Middle (30 - 49 years)	No	3.3	-11.1	8.5				
3140	3	Female	Middle (30 - 49 years)	No	3.1	-12.5	8.7				

3141	3	Female	Middle (30 - 49 years)	No	3.1	-13.2	9.1				
3148	4	Male	Middle (30 - 49 years)	Yes							
3149	4	Male	Middle (30 - 49 years)	No				-5.7			-7.9
3151	0	Male	Middle (30 - 49 years)	No	3.3	-11.3	10.4	-6	5.3	-16.6	-9.2
3154	3	Male	Middle (30 - 49 years)	No	3.3	-10.9	10.5	-6	4.9	-16.0	-8.3
3155	3	Male	Middle (30 - 49 years)	Yes	3.4	-11.8	9.9	-6.9	4.9	-16.7	-8
3158	0	Male	Young (18 - 29 years)	No	3.4	-11.5	9.6	-5.8	5.7	-17.0	-7.2
3160	4	Male	Middle (30 - 49 years)	No	3.6	-11.7	9.8	-6.5	5.2	-16.8	-9.6
3161	4	Male	Older (50 + years)	No				-4.1			-7.6
3162	4	Male	Older (50 + years)	No	3.3	-12.3	10	-7.6	4.7	-17.0	-10
3164	4	Male	Young (18 - 29 years)	No	3.4	-8.2	9.9	-4.7	3.5	-13.1	-8.3
3165	4	Ambiguous or Indeterminate	Middle (30 - 49 years)	No				-6.7			-9.2
3166	4	Male	Middle (30 - 49 years)	No	3.4	-10.2	9.9	-5.9	4.3	-15.2	-7.8
3170	4	Male	Middle (30 - 49 years)	No	3.5	-11.4	10	-5.8	5.6	-16.8	-6.5
3184	4	Male	Older (50 + years)	No	3.4	-11	9.6				
3185	4	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	3.3	-12.8	8.6				
3186	4	Male	Middle (30 - 49 years)	No	3.3	-11	9.4				
3189	4	Female	Young (18 - 29 years)	No	3.3	-12	9.6	-5.9	6.1	-17.6	-8.1
3191	4	Male	Young (18 - 29 years)	No	3.6	-10.4	9.2	-4.7	5.7	-16.1	-8.4
3199	4	Male	Middle (30 - 49 years)	No	3.3	-12.1	9.7	-6.6	5.5	-17.3	-7.6
3202	4	Male	Older (50 + years)	No	3.2	-13.4	9.4	-7.6	5.8	-18.5	-8.1
3215	4	Female	Young (18 - 29 years)	No	3.4	-11.2	10.2	-4.9	6.3	-17.1	-7.2
3218	4	Female	Middle (30 - 49 years)	No	3.5	-13.6	9.5	-8.4	5.2	-18.3	-7.3
3220	4	Female	Middle (30 - 49 years)	No	3.1	-13	9.3				
3222	4	Female	Middle (30 - 49 years)	No	3.2	-12.8	9.1	-7	5.8	-18.0	-7.2
3225	4	Male	Middle (30 - 49 years)	No	3.5	-13.3	10.1	-6.8	6.5	-18.8	-7.6
3226	4	Female	Young (18 - 29 years)	No	3.4	-12.1	9.1	-7	5.1	-17.1	-9.5
3229	4	Male	Middle (30 - 49 years)	No	3.6	-11.4	9.9	-6.3	5.1	-16.6	-8.1
3234	4	Female	Young (18 - 29 years)	No	3.6	-11.9	8.7	-6.8	5.1	-16.9	-7.8
3235	4	Male	Middle (30 - 49 years)	Yes	3.2	-11.8	10				
3236	4	Female	Older (50 + years)	Yes	3.4	-12.1	9.6	-6.3	5.8	-17.5	-9.6
3242	4	Male	Young (18 - 29 years)	Yes	3.3	-12.9	9.5	-7.7	5.2	-17.8	-8.3
3245	4	Female	Middle (30 - 49 years)	No	3.5	-12.6	10.1	-7.1	5.5	-17.7	-9.1
3248	4	Male	Middle (30 - 49 years)	No	3.3	-12.6	10	-7	5.6	-17.8	-6.3
3250	4	Male	Middle (30 - 49 years)	No	3.2	-13.7	8.9				
3251	4	Female	Middle (30 - 49 years)	No	3.4	-13.7	9.4	-9.1	4.6	-18.1	-8.1
3263	4	Male	Older (50 + years)	Yes	3.4	-11.7	9.8	-6.8	4.9	-16.7	-9.2
3264	4	Female	Older (50 + years)	Yes	3.2	-11.5	9.8	-6.3	5.2	-16.7	-7.9

3266	4	Female	Middle (30 - 49 years)	No	3.4	-13	8.8				
3268	4	Male	Middle (30 - 49 years)	No	3.4	-11.3	9.2	-6.5	4.8	-16.3	-7.8
3271	4	Male	Middle (30 - 49 years)	No	3.3	-13.4	9.8	-7.7	5.7	-18.5	-7.1
3272	4	Male	Middle (30 - 49 years)	Yes	3.4	-10.1	10	-5.4	4.7	-15.3	-8.4
3274	4	Male	Middle (30 - 49 years)	No	3.3	-9.7	9.3	-5.5	4.2	-14.7	-7.5
3276	4	Male	Middle (30 - 49 years)	No	3.3	-11.1	9.6	-6.6	4.5	-16.0	-8.4
3277	4	Female	Young (18 - 29 years)	No	3.6	-12	9.4	-5.5	6.5	-17.8	-7.7
3286	4	Ambiguous or Indeterminate	Young (18 - 29 years)	Yes	3.3	-11.9	8.7	-6.8	5.1	-16.9	-8.2
3287	4	Male	Middle (30 - 49 years)	No	3.5	-10.7	9.3	-5.1	5.6	-16.3	-7.6
3291	4	Male	Middle (30 - 49 years)	No	3.5	-11.8	10.4				
3296	4	Female	Middle (30 - 49 years)	Yes	3.2	-13.7	9.4	-7.8	5.9	-18.8	-8.2
3299	4	Female	Older (50 + years)	Yes	3.6	-13.8	9.4				
3303	4	Male	Older (50 + years)	No	3.5	-11	9.9	-6.1	4.9	-16.1	-8.8
3327	4	Female	Middle (30 - 49 years)	No	3.5	-13	9.5	-7	6	-18.3	-7.9
3334	4	Female	Young (18 - 29 years)	No	3.6	-12	9.3	-5.7	6.3	-17.7	-8.5
3336	4	Male	Middle (30 - 49 years)	No							
4524	1	Ambiguous or Indeterminate	Middle (30 - 49 years)	Yes	3.5	-10	10.9				
4525	1	Male	Middle (30 - 49 years)	No	3.6	-11.9	10.2				
4535	4	Male	Middle (30 - 49 years)	No				-5.8			-7.7
1054-b	1	Male	Young (18 - 29 years)	No	3.4	-11.1	7.7	-6.8	4.3	-15.9	-7.5
1054-d	1	Male	Middle (30 - 49 years)	No	3.2	-10.5	9.4	-6.3	4.2	-15.3	-8.5
1064-2	1	Ambiguous or Indeterminate	Young (18 - 29 years)	No							
1160-2	2	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	3.2	-10.9	10.2	-6.9	4	-15.5	-8.2
3175-2	4	Female	Young (18 - 29 years)	No	3.4	-11.5	9.9				
3203-2	4	Female	Middle (30 - 49 years)	No	3.3	-11.5	9.5				
3203-3	4	Male	Older (50 + years)	No	3.3	-14.3	9.8	-7.9	6.4	-19.6	-9.2
3305-2	4	Ambiguous or Indeterminate	Older (50 + years)	No	3.3	-13.4	9.1				
809-b	0	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	3.5	-14.4	9.9	-6.8	7.6	-20.3	-6.9

Appendix C: All Tibanica stable isotope data from teeth (reflecting childhood diet)

SAMPLE ID	BURIAL GROUP	SEX	Age Group	Grave Goods	Tooth Sampled	$\delta^{13}C$ (‰) Enamel	$\delta^{18}O$ (‰) Enamel	C/N (dentin crown)	$\delta^{13}C$ (‰) Dentin Collagen	$\delta^{15}N$ (‰) Dentin Collagen
50	2	Female	Older (50 + years)	No	M2	-5	-8.7	3.3	-11.2	9.7
52	2	Male	Young (18 - 29 years)	No	M2	-4.4	-10	3.3	-12.6	10.6
104	2	Ambiguous or Indeterminate	Middle (30 - 49 years)	Yes	M2	-5.2	-7.5	3.4	-12.6	9.3
105	2	Female	Middle (30 - 49 years)	No	M2	-3.7	-7.5	3.2	-11.4	11.7
114	2	Female	Older (50 + years)	No	M3	-5.8	-8.5	3.6	-13.4	10.4
117	2	Male	Older (50 + years)	No	M2	-4.9	-7.4	3.3	-11.8	10.4
118	2	Female	Young (18 - 29 years)	No	M2	-5.8	-7.2	3.2	-13.5	10.5
161	2	Male	Middle (30 - 49 years)	No	M2	-4.6	-7.8	3.6	-12.2	10.2
168	2	Female	Older (50 + years)	No	NO TEETH					
177	2	Male	Young (18 - 29 years)	No	PM	-2.8	-8.6	3.1	-10.4	12.4
192	2	Male	Middle (30 - 49 years)	No	M2	-4.6	-7.1	3.2	-12.1	10.4
195	2	Female	Middle (30 - 49 years)	Yes	M2	-4.2	-5.9	3.4	-11.9	9.9
198	2	Female	Middle (30 - 49 years)	No	M2	-3.5	-6.9	3.2	-11.5	10.3
245	0	Female	Middle (30 - 49 years)	Yes	M2	-4.9	-7.9	3.2	-13.7	10
802	0	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	M2	-3.9	-9.2	3.2	-11	12
811	1	Male	Young (18 - 29 years)	Yes	M2	-4.9	-7.5	3.3	-12.9	10.9
812	1	Ambiguous or Indeterminate	Young (18 - 29 years)	No	M2	-6.5	-6.7	3.6	-13.8	10.3
813	1	Female	Middle (30 - 49 years)	Yes	M2	-4.8	-7.4	3.1	-12.8	10.7
822	1	Male	Middle (30 - 49 years)	No	M2	-4.2	-7.2	3.3	-11.9	10.3
823	1	Male	Older (50 + years)	Yes	M1	-2.1	-6.3	3.2	-10.7	10.5
825	1	Ambiguous or Indeterminate	Young (18 - 29 years)	No	M2	-3.4	-7.8	3.5	-11.7	9.2
832	1	Male	Older (50 + years)	No	M2	-5	-7.4	3.1	-12.1	9.8
833	1	Male	Middle (30 - 49 years)	No	M2	-5.1	-7.5	3.4	-11.3	9.9
838	1	Male	Older (50 + years)	No	M2			3.2	-11.5	11

839	1	Ambiguous or Indeterminate	Older (50 + years)	No	NO TEETH					
841	1	Ambiguous or Indeterminate	Middle (30 - 49 years)	Yes	M2	-7.9	-9.3	3.2	-14	10.8
847	1	Female	Young (18 - 29 years)	No	M2	-3.6	-9.5	3.5	-10.6	8.6
851	1	Male	Middle (30 - 49 years)	No	M2	-5.3	-7.6	3.2	-12.3	10.1
902	1	Male	Middle (30 - 49 years)	No	M2	-3.6	-9.5	3.3	-10.6	10.8
903	1	Female	Young (18 - 29 years)	No	M2	-2.4	-8.5	3.2	-10.9	9.7
924	1	Female	Older (50 + years)	Yes	M2			3.1	-10.2	10.3
944	1	Male	Middle (30 - 49 years)	No	M2	-1.9	-9.9	3	-7.8	9.9
947	1	Male	Older (50 + years)	No	M3	-4.4	-8.3	3.3	-12.3	10.2
1021	1	Male	Middle (30 - 49 years)	Yes	M2	-5.4	-7.4	3.5	-12	9.4
1024	1	Female	Middle (30 - 49 years)	No	M2	-5.2	-7.8	3.5	-13.5	11.2
1026	1	Male	Middle (30 - 49 years)	Yes	M2	-4.1	-8.2	3.4	-11.2	9.7
1027	1	Female	Middle (30 - 49 years)	No	M3			3.1	-11.6	9.6
1050	1	Male	Middle (30 - 49 years)	No	M2	-2.9	-7.9	3.1	-10.8	9.9
1054	1	Male	Middle (30 - 49 years)	Yes	M2	-3.2	-8.4	3.2	-9.9	10
1057	1	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	M2	-5.7	-9.2	3.3	-13.5	10.5
1058	1	Ambiguous or Indeterminate	Young (18 - 29 years)	No	M2	-5.9	-7.6	3.4	-13.6	11.2
1061	1	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	M3	-3	-7.2	3.3	-10.9	9.9
1063	1	Female	Middle (30 - 49 years)	No	PM	-3.7	-7.1	3.4	-11.3	9.1
1065	1	Male	Middle (30 - 49 years)	No	M2	-2.7	-7.6	3.2	-10.2	9
1067	1	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	M2	-4.2	-7.7	3.3	-10.7	9.7
1069	1	Male	Young (18 - 29 years)	No	M2	-5.2	-8.9	3.3	-12.7	9.3
1153	2	Female	Older (50 + years)	No	M2	-7.6	-9.2	3.4	-14.1	9.9
1154	2	Female	Middle (30 - 49 years)	No	M2	-3.4	-8.6	3.2	-10.6	10.7
1155	2	Female	Young (18 - 29 years)	Yes	M2	-3.7	-7.8	3.2	-10.4	9.4

1156	2	Male	Middle (30 - 49 years)	Yes	M2	-5	-7.7	3.2	-11.3	10.2
1157	2	Female	Young (18 - 29 years)	Yes	M2	-5.4	-7.1	3.1	-12.3	9.5
1159	2	Female	Middle (30 - 49 years)	No	M2	-3.5	-8.2	3.2	-11.4	10.4
1163	2	Male	Middle (30 - 49 years)	No	M3	-1.2	-7.3	3.2	-8.7	10.8
1164	2	Female	Middle (30 - 49 years)	No	PM	-3.7	-8.2	3.1	-11.14	10.81
1166	2	Male	Middle (30 - 49 years)	No	M2	-5.6	-7.7	3.2	-12.8	9.8
1173	2	Male	Middle (30 - 49 years)	No	M2	-6	-8.1	3.3	-12.6	9.9
1174	2	Male	Middle (30 - 49 years)	No	M3	-1.7	-6.4	3.3	-8.9	8.8
1175	2	Female	Young (18 - 29 years)	No	PM	-7.2	-6.6	3.1	-13.5	8.9
1176	2	Female	Middle (30 - 49 years)	No	M3	-3	-8.1	3.1	-10.7	9.8
1177	2	Male	Older (50 + years)	No	M2	-3.7	-8.5	3.3	-8.7	10.3
1179	2	Male	Middle (30 - 49 years)	No	M2	-3.9	-8.1	3.2	-11.3	10.6
1185	2	Female	Middle (30 - 49 years)	No	M2	-5.9	-7.5	3.2	-12.7	10.9
1186	2	Female	Young (18 - 29 years)	Yes	M2	-3.2	-8.1	3.2	-11.4	10.4
1187	2	Female	Middle (30 - 49 years)	No	M2	-5.3	-6.8	3.2	-12	10.8
1188	2	Female	Middle (30 - 49 years)	Yes	M2	-4.2	-8.5	3.4	-11.1	10.5
1191	2	Female	Middle (30 - 49 years)	No	M3	-5.1	-7.9	3.3	-13.3	10.5
1194	2	Female	Young (18 - 29 years)	No	M2	-5.1	-7.7	3.6	-11.8	10.1
1196	2	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	M2	-4.2	-7.8	3.3	-11.6	9.7
1197	2	Male	Middle (30 - 49 years)	No	M2	-5.5	-7.1	3.3	-11.6	10.6
1198	2	Female	Middle (30 - 49 years)	No	M2	-3.4	-7.9	3.3	-9.4	11.4
1210	1	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	M3	-6.2	-7.3	3.3	-13	9.3
1211	1	Female	Middle (30 - 49 years)	No	I	-5.5	-8.1	3.4	-12.6	10.8
1222	1	Female	Older (50 + years)	No	M2	-5.9	-9.3	3.2	-13.4	9.8
1230	1	Female	Older (50 + years)	No	M2	-5.5	-6.1	3.2	-12.9	11
1231	1	Female	Older (50 + years)	No	PM	-4.7	-6.3			
1233	1	Male	Older (50 + years)	Yes	M2	-5.1	-8	3.5	-14.5	10.6

1846	3	Male	Middle (30 - 49 years)	No	M2	-4.1	-8.6	3.3	-10.7	10
1865	3	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	M2	-5.8	-7.6	3.2	-13.5	9.8
1874	3	Female	Middle (30 - 49 years)	No	PM	-3.6	-7.9	3.2	-10.96	10.01
2142	3	Female	Middle (30 - 49 years)	No	M3	-3.9	-8.9	3.2	-11.8	10.2
2143	3	Female	Older (50 + years)	No	M2	-3	-6.7	3.2	-10.3	11.7
2208	3	Male	Middle (30 - 49 years)	No	M3			3.5	-13.7	10.3
2808	0	Female	Young (18 - 29 years)	No	M2	-7.9	-8.1	3.6	-15.2	11.5
2809	0	Male	Middle (30 - 49 years)	No	M3	-2.7	-8.4	3.3	-9.7	9.8
2837	3	Male	Middle (30 - 49 years)	No	M3	-6.7	-7.5	3.3	-11.9	9.3
2847	3	Male	Older (50 + years)	No	M2	-6.3	-7.5	3.4	-13.3	9.2
2849	3	Male	Middle (30 - 49 years)	No	M2	-2.4	-7.4	3.6	-9.6	10.8
2850	3	Female	Middle (30 - 49 years)	Yes	M2	-5.9	-6.2	3	-12.8	9.7
2857	3	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	M3	-7	-7.8	3.2	-14.9	10.5
2859	3	Male	Middle (30 - 49 years)	Yes	M3	-4.2	-8.1	3.1	-10.7	10.2
2863	3	Male	Middle (30 - 49 years)	No	M2	-4.6	-7.2	3.2	-11.7	11.1
2865	3	Female	Middle (30 - 49 years)	No	M2	-4.4	-6.8	3.5	-13	11.1
2869	3	Male	Middle (30 - 49 years)	No	M2	-2.8	-6.8	3.2	-11.5	8.8
2871	3	Ambiguous or Indeterminate	Middle (30 - 49 years)	Yes	M2	-3.9	-7	3.2	-11.9	10.7
2873	3	Female	Middle (30 - 49 years)	No	M2	-3	-6.8	3.1	-10.3	10
2874	3	Ambiguous or Indeterminate	Young (18 - 29 years)	No	M2	-4.1	-7.1	3.4	-12.3	10.6
2876	3	Male	Middle (30 - 49 years)	No	M2	-3.8	-7.6	3.5	-11.7	9.6
2878	3	Female	Older (50 + years)	No	PM	-5.3	-7.2	3.2	-12.7	11.4
2881	3	Female	Older (50 + years)	No	M3	-2.9	-7.2	3.2	-10.3	9.9
2885	3	Male	Middle (30 - 49 years)	No	PM	-4.4	-7	3.2	-11.1	9.8
2886	3	Ambiguous or Indeterminate	Young (18 - 29 years)	Yes	M2	-4.6	-8.6	3.3	-11.8	8
2887	3	Female	Middle (30 - 49 years)	No	M3	-4.1	-6.4	3.2	-12.8	10.2

2888	3	Male	Middle (30 - 49 years)	Yes	M3	-3.5	-7.3	3.5	-13.3	10.7
2891	3	Male	Young (18 - 29 years)	Yes	M1	-5.2	-7.8	3.3	-12.2	10.3
2892	3	Female	Middle (30 - 49 years)	No	M3	-5.4	-4.9	3.2	-11.9	10.7
2896	3	Ambiguous or Indeterminate	Young (18 - 29 years)	Yes	M3	-4.7	-7.8	3.3	-11.2	10.5
2897	3	Male	Middle (30 - 49 years)	Yes	M2	-2.5	-6.8	3.4	-11.1	11.1
2933	3	Ambiguous or Indeterminate	Older (50 + years)	No	M2	-3.9	-7.9	3.4	-12.8	12
2934	3	Male	Middle (30 - 49 years)	No	M2	-5.2	-8.1	3.3	-13.3	9.9
2935	3	Male	Middle (30 - 49 years)	No	M2	-4.3	-7.3	3.2	-11.7	11
2936	3	Female	Middle (30 - 49 years)	No	M2	-3.4	-7.3	3.4	-10.9	8.5
3020	1	Male	Middle (30 - 49 years)	Yes	M2	-2.7	-7	3.2	-9.5	10.1
3100	3	Male	Middle (30 - 49 years)	No	M2	-3.1	-6.5	3.4	-10.1	10.3
3102	3	Female	Middle (30 - 49 years)	Yes	M3	-6.5	-7.9	3.1	-13.2	10.9
3103	3	Male	Older (50 + years)	No	M3	-3.3	-7.4	3.6	-10	10.9
3106	3	Male	Middle (30 - 49 years)	No	M2	-2.2	-8.2	3.1	-11.1	9.2
3108	3	Female	Young (18 - 29 years)	No	M2	-1.8	-5.2	3.1	-9.6	9.9
3111	3	Female	Middle (30 - 49 years)	No	M2	-5	-6.1	3.3	-13	12.5
3112	3	Male	Middle (30 - 49 years)	Yes	M2	-3.8	-7.3	3.1	-10.7	9.4
3117	3	Male	Middle (30 - 49 years)	Yes	M2	-3.4	-8	3.3	-10.7	10.7
3118	3	Male	Older (50 + years)	No	M2	-4.2	-8.6	3.3	-11.3	10.9
3119	0	Male	Young (18 - 29 years)	No	M2	-3.2	-7.7	3.2	-10.6	10.7
3124	3	Female	Middle (30 - 49 years)	No	M3	-4.1	-8.2	3.5	-11.6	10.3
3126	3	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	M2	-6.1	-6.7	3.5	-13.9	10.4
3127	3	Male	Middle (30 - 49 years)	No	M3	-4.9	-8.5	3.3	-11.7	11.1
3128	3	Male	Middle (30 - 49 years)	No	M3	-3.6	-7.3	3.2	-11.2	10.8
3129	3	Male	Older (50 + years)	No	M2	-2.6	-7.1	3.3	-11.5	10.7
3130	3	Female	Young (18 - 29 years)	No	M2	-3.5	-7	3.4	-11.7	10.3
3133	3	Male	Middle (30 - 49 years)	No	M2	-4	-6.8	3.3	-11.1	11.9

3134	3	Male	Middle (30 - 49 years)	No	M1	-2.5	-7.9	3.4	-10.2	9.4
3135	3	Male	Young (18 - 29 years)	No	M3	-1.5	-7.9	3.2	-8.7	10.4
3136	3	Female	Middle (30 - 49 years)	No	M3	-5	-7.4	3.5	-12	9.4
3140	3	Female	Middle (30 - 49 years)	No	M2	-5.7	-6.9	3.3	-13	9.1
3141	3	Female	Middle (30 - 49 years)	No	M3	-5.7	-7.3	3.3	-14.2	10.6
3148	4	Male	Middle (30 - 49 years)	Yes	M2	-6.5	-6.4	3.3	-13	10.2
3149	4	Male	Middle (30 - 49 years)	No	M2	-3.9	-7.8	3.5	-11.1	9.7
3151	0	Male	Middle (30 - 49 years)	No	M2	-3.1	-8.2	3.3	-11.62	11.58
3154	3	Male	Middle (30 - 49 years)	No	M3	-1.7	-7.4	3.2	-9.3	10.9
3155	3	Male	Middle (30 - 49 years)	Yes	M2	-5.1	-6.6	3.3	-12.7	9.8
3158	0	Male	Young (18 - 29 years)	No	M2	-3.4	-7.7	3.6	-10.6	10
3160	4	Male	Middle (30 - 49 years)	No	M2	-5.5	-8.2	3.4	-12.8	10.2
3161	4	Male	Older (50 + years)	No	M2	-2	-8.3	3.2	-8.65	10.74
3162	4	Male	Older (50 + years)	No	M3	-3.6	-8.6	3.3	-11	10.7
3164	4	Male	Young (18 - 29 years)	No	M2	-3.7	-8.5	3.4	-11.1	10
3165	4	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	M2	-6.1	-7	3.5	-13.4	10.1
3166	4	Male	Middle (30 - 49 years)	No	M3	-3.7	-8.5	3.3	-11	9.8
3170	4	Male	Middle (30 - 49 years)	No	M3	-4.4	-7.5	3.5	-11.3	10.4
3184	4	Male	Older (50 + years)	No	M3	-3.2	-8.1	3.3	-10.7	9.7
3185	4	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	M2	-4.9	-7.2	3.4	-12.5	9.3
3186	4	Male	Middle (30 - 49 years)	No	M2	-3.5	-7.6	3.3	-10.6	10.4
3189	4	Female	Young (18 - 29 years)	No	M2	-5.7	-8.4	3.6	-12.7	10.9
3191	4	Male	Young (18 - 29 years)	No	M2	-3.3	-7.4	3.1	-11	9.8
3199	4	Male	Middle (30 - 49 years)	No	M2	-5.7	-9.3	3.2	-12.9	10.2
3202	4	Male	Older (50 + years)	No	M3	-5.2	-9.5	3.2	-12.24	10.13
3215	4	Female	Young (18 - 29 years)	No	M2	-3	-8	3.1	-10.9	10.6
3218	4	Female	Middle (30 - 49 years)	No	M2	-5.8	-8.5	3.5	-12.6	10.4

3220	4	Female	Middle (30 - 49 years)	No	M2	-5	-7.9	3.2	-12.6	10
3222	4	Female	Middle (30 - 49 years)	No	M3	-4.8	-8.6	3.1	-12.4	10.1
3225	4	Male	Middle (30 - 49 years)	No	PM	-4.3	-7.8	3.2	-12.7	11.8
3226	4	Female	Young (18 - 29 years)	No	M3	-4.8	-7.9	3.2	-12.9	10.9
3229	4	Male	Middle (30 - 49 years)	No	M3	-5.1	-7.3	3.6	-10.7	10.5
3234	4	Female	Young (18 - 29 years)	No	M2	-2.7	-6.6	3.2	-11.6	10
3235	4	Male	Middle (30 - 49 years)	Yes	M2	-6.1	-8.2	3.1	-14.1	10.7
3236	4	Female	Older (50 + years)	Yes	M2	-4.9	-8	3.3	-12.4	10.8
3242	4	Male	Young (18 - 29 years)	Yes	M2	-5.9	-7.9	3.1	-13	10.3
3245	4	Female	Middle (30 - 49 years)	No	M2	-6.4	-8	3.2	-14.4	10.1
3248	4	Male	Middle (30 - 49 years)	No	M1	-7.2	-7.9	3.3	-13.5	11.1
3250	4	Male	Middle (30 - 49 years)	No	M3	-3.7	-7.2	3.5	-11.7	10.3
3251	4	Female	Middle (30 - 49 years)	No	PM	-3.5	-6.9	3.3	-11.4	10.4
3263	4	Male	Older (50 + years)	Yes	M2	-4.3	-7	3.5	-11.5	10.4
3264	4	Female	Older (50 + years)	Yes	M1	-3.7	-7.5	3.2	-11.9	11.2
3266	4	Female	Middle (30 - 49 years)	No	M2	-5.3	-8.2	3.2	-13.1	10.4
3268	4	Male	Middle (30 - 49 years)	No	M2	-3.7	-7	2.9	-12	10.4
3271	4	Male	Middle (30 - 49 years)	No	M3	-6.4	-7.8	3.1	-13.4	10.7
3272	4	Male	Middle (30 - 49 years)	Yes	M2	-3.5	-8.1	3.4	-10.7	10.5
3274	4	Male	Middle (30 - 49 years)	No	M3	-3.2	-7.4	3.4	-10.2	10.1
3276	4	Male	Middle (30 - 49 years)	No	M2	-4.9	-7.2	3.2	-11.5	10.1
3277	4	Female	Young (18 - 29 years)	No	NO TEETH					
3286	4	Ambiguous or Indeterminate	Young (18 - 29 years)	Yes	M2	-5.2	-7.3	3.3	-11.8	9.9
3287	4	Male	Middle (30 - 49 years)	No	M2	-3.1	-8.6	3.4	-11.8	9.6
3291	4	Male	Middle (30 - 49 years)	No	M2	-5.5	-7.6	3.3	-13.4	10.4
3296	4	Female	Middle (30 - 49 years)	Yes	M2	-6.01	-8.56	3.1	-13.34	10.22
3299	4	Female	Older (50 + years)	Yes	M2	-5.1	-7.3	3.3	-13.6	10.2

3303	4	Male	Older (50 + years)	No	M2	-2.1	-6.6	3.5	-9.6	10.1
3327	4	Female	Middle (30 - 49 years)	No	M3	-3.9	-8	3.2	-11.5	10.3
3334	4	Female	Young (18 - 29 years)	No	PM	-5.6	-9.6	3.1	-13.1	8.7
3336	4	Male	Middle (30 - 49 years)	No	M2	-4	-6.8	3.4	-11.5	8.8
4524	1	Ambiguous or Indeterminate	Middle (30 - 49 years)	Yes	M2	-5.7	-6.2	3.3	-13	10
4525	1	Male	Middle (30 - 49 years)	No	M3	-1.8	-6.2	3.2	-9	9.9
4535	4	Male	Middle (30 - 49 years)	No	M2	-6.5	-7.6	3.5	-11.6	10.3
1054-b	1	Male	Young (18 - 29 years)	No	M2	-3.9	-6.1	3.3	-11.3	8
1054-d	1	Male	Middle (30 - 49 years)	No	M2	-4.1	-7	3.6	-11.6	11.3
1064-2	1	Ambiguous or Indeterminate	Young (18 - 29 years)	No	M2	-2.8	-7.5	3.2	-9.9	10
1160-2	2	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	M2	-4.2	-7.4	3.2	-11.5	10.7
3175-2	4	Female	Young (18 - 29 years)	No	M2	-4.5	-7.9	3.2	-12.41	11.1
3203-2	4	Female	Middle (30 - 49 years)	No	NO TEETH					
3203-3	4	Male	Older (50 + years)	No	NO TEETH					
3305-2	4	Ambiguous or Indeterminate	Older (50 + years)	No	PM	-7.2	-8.8	3.3	-13.7	9.7
809-b	0	Ambiguous or Indeterminate	Middle (30 - 49 years)	No	M2	-2.8	-6.6	3.4	-10.5	11.9