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**SPANISH MISSIONIZATION AND MAYA SOCIAL STRUCTURE:
SKELETAL EVIDENCE FOR LABOR DISTRIBUTION AT TIPU, BELIZE**

by

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B.A., Anthropology, University of Wyoming, 2004
M.S., Anthropology, University of New Mexico, 2008

DISSERTATION

Submitted in Partial Fulfillment of the
Requirements for the Degree of

Doctor of Philosophy

Anthropology

The University of New Mexico
Albuquerque, New Mexico

May, 2013

Dedication

To Larry, Dani and Maria, for the love and support that are the foundation of my strengths, and the encouragement that surmounts my weaknesses.

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Abstract

The cultural and human biological outcomes of Spanish colonization of the Americas were diverse. This dissertation examines the effects of Spanish colonization on Maya social structure using skeletal evidence for the distribution of labor at Tipu, a mission site in west central Belize. Skeletal remains of indigenous Maya buried in the context of a church, and in accordance with European Catholic burial customs, were examined for entheses development and the cross-sectional morphology (CSG) of upper and lower limb long bones. Nothing besides burial placement in relation to the church (inside or outside the walls) denotes social status among individuals. Bone functional adaptations were used to examine the distribution of labor at Tipu and determine whether activity patterns varied by burial placement, and therefore social status. The bone functional adaptations of samples of pre-contact Maya elite and non-elites were also examined to determine whether the activity patterns of high and low status individuals at Tipu varied in the same way as those of Classic/Postclassic Maya of different social tiers.

A 3D laser scanner was used to measure the surface areas of entheses on the humerus, radius and ulna, as well as CSG of the humerus (at 35% of length), femur and tibia (at midshaft). Detailed in this dissertation are: 1) a pilot study testing the reliability of the new 3D method for quantifying entheses development, 2) an investigation of the distribution of labor at Tipu using entheses as indicators of habitual upper limb muscle use, and 3) an investigation of labor distribution at Tipu using CSG as indication of habitual upper limb use and mobility patterns.

The pilot study presented in Chapter 2 supports the use of the 3D method for quantifying enthesis development. Chapters 3 and 4 demonstrate that both patterns of enthesis development and CSG at Tipu suggest Maya social structure changed with missionization. The activity patterns of high and low status individuals did not replicate those of pre-contact elites and non-elites. In general, the activity patterns of Tipuans of different social status were more similar. There were no drastic differences in the bone functional adaptations of inside and outside burial groups. However, some notable exceptions to this finding in both enthesis development and CSG suggest there may have been some task specialization among higher status Tipu men and women.

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Chapter 1.

Introduction

The variety of indigenous cultures and environments that were impacted by Spanish colonization of the Americas made each colonial scenario unique. This dissertation is an example of the case by case approach necessary to understand colonization's cultural and human biological effects (Lightfoot, 2006). The focus is on how Maya social hierarchy was affected by Spanish contact at Tipu, a Belize mission town in the frontier zone of the southern Lowlands. Tipu was a long-standing community that was made a *visita* mission in 1544 (Graham, 1998; Jones, 1989; 1998). Archaeological and historical sources suggest complete acceptance of Christianity by indigenous Maya there, but also maintenance of pre-existing ties with the powerful, unconquered Itzá Maya to the west (Jones, 1989; 1998). The town was an *encomienda* and therefore responsible for payment of tribute to Spaniards, but it seems that colonization did not require changes in labor demands, and pre-contact subsistence strategies continued (Cohen et al., 1994a; 1994b; Deagan, 2003; Emery, 1999; Graham, 1991; 1998; 2011; Jones, 1982).

Bioarchaeological analyses of the burials at Tipu have added much to the history of the village, but the Colonial Period social dynamics of the Tipu Maya still remain vague because nothing other than burial placement has been found to be indicative of status (Cohen et al., 1994b; Danforth et al., 1997; Jacobi, 2000; Graham et al., 1985; Wrobel, 2003). The interment of indigenous Maya in and around a mission church, in accordance with European Catholic burial customs, implies that a social hierarchy existed. However, continuity in subsistence strategies, maintained connections to trade networks, and regular contact with the Itzá Maya, suggest that missionization's only socio-cultural impact was the establishment of Christianity. The conclusion that there were no other societal consequences seems unreasonable, especially considering that people at Tipu accepted and maintained the practice of Christianity in a region that was

the battleground for violent power struggles between the Spanish and one of the last unconquered Maya kingdoms.

Although this study does not investigate every possible avenue for socio-cultural change caused by Spanish colonization, it is an attempt to illuminate the nature of the Colonial Period Maya social hierarchy at Tipu. Presented here is another line of evidence for exploring the nature of the social hierarchy that existed at Tipu after missionization. Skeletal signatures of activity, or bone functional adaptations, are assumed to be indicators of social status because Maya of disparate social tiers would have had different lifestyles due to different labor requirements (Adams, 1970; Chase and Chase, 1992; Inomata and Triadan, 2000). Analysis of bone functional adaptations in relation to burial location at Tipu (inside and outside the walls of the church) is the primary method employed. Bone functional adaptations observed in comparative samples of pre-contact elites and non-elites provide a basis on which to evaluate variation in skeletal morphology at Tipu. Osteological evidence for homogeneity in health and long bone robusticity, and lack of burial goods that are indicative of status (Cohen et al., 1994b; Danforth et al., 1997; Jacobi, 2000; Graham et al., 1985; Wrobel, 2003), lead to the general hypothesis that the highly stratified social structure of pre-contact times no longer existed. While there was a social hierarchy within the community indoctrinated into the church, the lifestyles of community leaders were not drastically different from the lifestyles of other members of the farming village.

This introduction provides a brief outline of the following three chapters that explore this topic and the research questions they address. Information about Tipu's spatial and temporal context is given through description of the site's geographical location, Pre-Columbian cultural features, and historical and archaeological records. The types of data used to address these questions are outlined as are the underlying assumptions being made and theoretical concepts that will govern interpretations of analyses.

Research Questions

The broad topic of interest is the social impact of Spanish missionization on the Maya at Tipu. To address it, this dissertation uses bone functional adaptations to investigate the distribution of labor among Tipu burial groups, and therefore the nature of the community's Colonial Period social structure. Bone functional adaptations studied include enthesis development and the cross-sectional morphology of long bones. Because the method used to measure enthesis development is not widely used (Nolte and Wilczak, 2010), Chapter 2 is an evaluation of its utility. After establishing the validity of the new method, Chapters 3 and 4 investigate patterns of variation in bone functional adaptations among the Maya at Tipu. Chapter 3 investigates variation in the development of upper limb entheses among Tipu burial groups and pre-contact elites and non-elites to assess variation in upper limb muscle use. Chapter 4 investigates variation in the cross-sectional geometry of humeri, femora, and tibiae among the same burial groups to assess variation in mobility patterns and upper limb robusticity. Both Chapters 3 and 4 do this through addressing the following research questions:

- 1) Are there significant differences in the bone functional adaptations of pre-contact elites and non-elites?
- 2) Are there significant differences in bone functional adaptations among burial groups at Tipu?
- 3) How do the bone functional adaptations of the Tipu burial sample compare to pre-contact Maya elites and non-elites?

Answering the first research question establishes how different the samples of pre-contact Maya from disparate social tiers actually are in bone functional adaptations and therefore provides a basis of comparison on which question three will be answered. The second and third questions are aimed at determining whether there is skeletal evidence of distinct social tiers at Tipu. For instance, it is expected that people of higher status would have engaged in less manual labor and therefore individuals buried inside the church structure

should have different patterns of entesis development than people of lower status interred outside the church walls. Question three determines whether the activity patterns of Tipuans were more similar to pre-contact elites or non-elites and whether this varied by burial location. It will provide further evidence for possible social stratification and will allow inferences to be made about whether a pre-contact social structure remained intact during the Colonial Period, or whether missionization created a new social sphere where commoners could become community leaders (Farriss, 1984).

It should be noted that this is a simplified, working model and that a variety of factors, discussed in more detail below, could have contributed to the distribution of burials at Tipu. It is also understood that a dichotomous view of the Maya as either elite or non-elite, high or low status, is not necessarily representative of their pre- or post-contact society (Chase, 1992). However, the nature of both pre-contact comparative samples and the Tipu burial sample, and the nature of skeletal indicators of activity, do not allow examination of gradations in social status in this study. Pre-contact comparative samples were deliberately chosen to represent individuals at opposite ends of the Maya social pyramid, in order to determine whether their lifestyles were drastically different, as we often assume. These samples were also chosen with the idea that they would create the most contrast between pre- and post-contact social organization if there was in fact a reorganization of society within the Christianized Maya community at Tipu. Throughout this dissertation pre-contact comparative samples are referred to as elite or non-elite, with the understanding that this is a simplified representation of Maya society. Elite refers to individuals who would have had more prestige, power and wealth than the rest of pre-contact Maya society (Chase and Chase, 1992; Sanders, 1992). Non-elite refers to individuals from rural, agricultural communities that were subsidiary to major Classic/Postclassic centers of political/economic power. Individuals at Tipu are referred to as high or low status based on their burial location inside or outside the church walls, respectively, again with the understanding that this is likely a simplified representation of their social status. Reference to Tipuans as either high or low status, rather than elite or non-elite, is meant to signify that it is not assumed that these pre-contact social tiers persisted in the Colonial Period.

Background: Historical and Archaeological

Pre-Contact Maya Lifeways

It is important to understand Tipu's spatial and temporal context as a Maya community before contact in order to understand the nature of colonial encounters and how the community responded to Christianization (Lightfoot, 2006; Stein, 2005). Occupation of Tipu began in the Preclassic around 300 BC and was continuous throughout the Classic, Postclassic and Colonial time periods (Graham, 1991; Cohen et al., 1994a). Therefore, Tipu represents a well-established and enduring Maya community with no periods of abandonment. Most relevant here is consideration of cultural trends and the social climate surrounding Tipu during the Terminal Classic and Postclassic time periods.

Lowland Political and Socioeconomic Organization in the Terminal Classic and Postclassic

In the Terminal and Postclassic, the Maya Lowlands were characterized by a series of dynamic sociopolitical alliances and dominance relations where links between major centers and smaller communities involved long distance exchange and migration events (Cecil, 2009a). Although many regions experienced population decline and many city centers were abandoned in the Terminal Classic (AD 300-950) (Demarest, 2004), the depopulation of major centers was not homogenous (Cecil, 2009a; LeCount et al., 2002). The description of the Terminal Classic as a time of collapse is therefore misleading (Chase and Rice, 1985; Rice, 2000; Cecil, 2009a). Urban centers in the Maya Lowlands were not completely abandoned everywhere all at once and there was no single event that caused "catastrophic collapse". Throughout Maya history centers rose and fell depending on population sizes and the sustainability of those populations given a set of limiting environmental factors (Demarest, 2004; Pendergast, 1990). Examples of such factors include agricultural productivity of a landscape, conflict and warfare among polities, and

the reasonability of elite demands for resources. The mis-characterization of the Terminal Classic as a period of catastrophe can be traced to the 1940s when drastic changes were first observed in the archaeological record (Chase and Rice, 1985; Rice, 2000; Cecil, 2009a). These changes signified a major reorganization event in the Southern Lowlands (~900 BC) that was characterized by cessation of several cultural traits that typified Classic Period Maya worldviews (Rice, 2000; Rice, 2009). Conspicuous consumption of prestige items declined among elites. Carved and dated stelae were no longer created and elite focus on the creation of monumental architecture declined. Use of polychrome painted pottery, the creation of elaborate tombs for elites and use of the Long Count calendar also ceased, which suggests replacement of concepts of divine kingship with a more secular government (Rice, 2000; Rice, 2009).

In the Postclassic, many city-states experienced decreases in centralization and hierarchical reorganizations that resulted in a shift toward semi-autonomous, small provincial centers that were part of political territories (LeCount, 2001; Masson, 2000a). Political power was still expressed by elite members of society who retained some autonomy and elite lineages were still celebrated; however, power was performed in a greater diversity of outlets including sculpture and murals (Masson, 2000a). The Maya social pyramid was reoriented so that there was not one divine lord at the top, but a rather a council of rulers, which is known as the *multepal* system (Rice, 2009). In many regions there was also a decentralization of Maya ritual (Graham, 2009). The performance of ritual still seems to have been the duty of a select few (Masson, 2000b), but it was no longer strictly reserved for dynastic rulers (Graham, 2009).

Postclassic socioeconomic transitions are observable through change in commodity production and distribution (Rice, 2000). Elites no longer had ultimate control of ritual and a heavy influence on economy. Instead, they mostly controlled ritual and promoted economy by holding market events (Masson, 2000a; 2000b). Although production was community-centered in the Classic Period, it was left up to communities even more during the Postclassic and there was no evidence of a prestige economy (Masson, 2000a). While there were not as many large powerful centers in the Postclassic (LeCount, 2001; Masson, 1999), and trade networks for prestige items changed due to

decline in conspicuous consumption among elites (Rice, 2000), hierarchical urban lifeways did continue in the Yucatan and southern Lowlands (Graham, 2011; LeCount et al., 2002; Masson, 2000a). Lowland Maya society remained complex and affluent, the Postclassic Maya codex tradition indicates writing and astronomy were still practiced, and in some cases, environmental rejuvenation is evident (LeCount et al., 2002; Masson, 1999; 2000a).

Tipu's Terminal Classic and Postclassic Context

In the Postclassic, the most powerful centers were Mayapan and Chichen Itzá (Masson, 2000a; Palma, 2004). Smaller centers included Lamanai (east of Tipu) and Nojpeten (also called Tah Itzá) of the Petén Lakes region, located on what is now the island of Flores in Guatemala (Masson, 2000a). Lamanai and Nojpeten were ultimately linked to Mayapan and Chichen Itzá through trade, and the Itzá of Nojpeten claimed descent from Chichen Itzá (Jones, 1998). As a link between Lamanai and the Petén Lakes region, Tipu was an integral part of the thriving trade networks and domains of rulership that existed during the Postclassic in what is now Belize (Graham, 2011). The persistence and growth of such smaller centers along coastal and inland trade routes, despite the decline of Chichen Itzá (AD 1000-1150), attests to the increased de-centralization of Maya polities in the Postclassic. The prosperity of communities no longer relied heavily on dynastic strength. Their success was largely due to participation in trade networks that operated independently from political institutions, yet continued to uphold the tribute system (Graham, 2011).

Like other communities in Belize, Tipu was part of a *cuchcabal*, or tribute network, extant and in operation long before contact. Spaniards ethnocentrically translated *cuchcabal* as states and their territorial boundaries. They were also referred to as *senorios*, which implied that the people within a demarcated province were obligated to pay tribute to the political center of that particular area (Graham, 2011). The Maya system of governance did represent hierarchical tribute and administrative networks, but these networks were centered on a particular rulership, not a certain political center with

strict territorial boundaries. The allegiance of a community was to particular rulers who owned what the land produced (i.e. tribute payments), but not the land itself. In other words, political power in the Late Postclassic was based on control of resources and acquiring rights to what was produced in a given *cuchcabal* (Graham, 2011). In Spanish accounts of Maya political organization, which were partly informed by indigenous Maya (Farriss, 1984), the lords of a *cuchcabal* were called *caciques*. Under *caciques* were *batabs*, which was the Yucatec Maya name for a kind of governor, who presided over a *cah* (municipality). The *batab* of a *cah* that grew to dominate a region was given the title *halach uinic*, which signified he held a position over the other *batabs* in a region (Graham, 2011).

Historical and archaeological records do not specify how exactly Tipu fit into the region's *cuchcabal* system and therefore the regional hierarchy in Belize (Graham, 2011). Historical documents that describe Belize in the 16th century are lacking. It is also difficult to determine the direction of tribute flow from distributions of material culture alone (Graham, 2011). However, a general illustration can be made. Tipu was documented as part of the Dzuluinicob province in Belize, which extended from the Northern River Lagoon to the Macal River and as far east as Lamanai (Cecil, 2009b). Historical sources indicate close ties and intermarriage between Tipuans and the Itzá of the Petén Lakes region during the Postclassic, and possibly since the Classic (Cecil, 2009b; Jones, 1998; 1977; Sholes and Thompson, 1977). However, Spanish accounts indicate that Tipuans defined themselves as ethnically different from the Itzá (Cecil, 2009b). When Tipu became a mission, the Itzás, Kowojs, Kejaches and Mopans were the major Yucatec Maya-speaking territorial groups in the Petén region. Spaniards documented the Itzás and Kowojs as the dominant socio-political groups (Jones, 1998). Tipu was located in Kowoj territory, and while there is evidence of interaction with the Kowoj, they seem to have interacted more with the Itzá, which is likely due to the later arrival of the Kowoj around 1530 (Cecil, 2009b). Evidence of intermarriage with Itzás comes from a census taken at Tipu in 1655, which lists 30 individuals who had Itzá and Yucatec compound names under the column heading "Tipuj-Itzás". These names also included members of the Kan lineage, which was the ruling lineage of the Itzá during the

Postclassic and Colonial Periods (Jones, 1998; Sholes and Thompson, 1977). Jones (1998) sees the intermarriage of Itzá and Tipuans, and the presence of elite Itzá representatives at Tipu, as evidence that Tipu was a subsidiary city of the major Itzá center of Nojpeten (Graham, 2011).

Many lines of evidence indicate that while Maya hierarchies and expressions of Maya ritual were reorganized during the Postclassic (LeCount, 2001; Masson, 1999; Pendergast, 1990; 1991; Rice, 2000), a complex hierarchy continued to exist (Masson, 2000a; Rice, 2009). Intensive interaction with the Itzá as well as Tipu's integrative role in the Dzuluinicob province indicates the community remained part of a highly stratified culture and Maya worldviews persisted well into the Colonial Period. Urban lifeways, the *cuchcabal* system, and ritual continued under elite lineages and trade networks thrived (Cecil, 2009; Graham, 2011; Graham, 2009; Masson, 2000a; 2000b; LeCount et al., 2002).

The Historical Record

The historical record of Spanish Colonization of the Yucatan and Belize is informed by several sources, the majority of which are the accounts of Spanish conquistadors and clergy. The best-known original Spanish accounts are those of Diego de Landa and a compilation of various *encomenderos'* answers to a royal questionnaire, titled *Relaciones Geográficas* (Farriss, 1984). Both works were informed by indigenous people but heavily reflect the views of the Spanish writers. The more recent work of historians has added much to the history of the Lowlands. Alfred Tozzer (1941), Ralph Roys (1943), Frances Scholes and J. Eric S. Thompson (1977), Inga Clendinnen (2003), Grant Jones (1977; 1989; 1998), Nancy Farriss (1984), Matthew Restall (eg. 1997, 2000), and Robert Patch (1993) have been major players in the exploration of Spanish and Maya historical sources and the consolidation of the historical record of Spanish conquest in the Lowlands. Most relevant to this dissertation are the works of Grant Jones (1977; 1989; 1998) because he has focused on the history of the region surrounding Tipu. His most recent book (Jones, 1998) is a history of the Petén Lakes region and the conquest of the

island kingdom of Nojpeten, which was one of the last, most powerful, Maya kingdoms that resisted Spanish control into the late 1600s. Tipu's ties to Nojpeten and the Itzá Maya through trade and marriage alliances meant the community was a pathway for Spanish efforts to conquer this last major center. Therefore, aside from records concerning Tipu's status as an *encomienda* and *visita* mission, the town's historical record is largely focused on its connections with the Itzá Maya. Jones' works (1977; 1989; 1998) are mainly informed by Juan de Villagutierre Soto-Mayor's *Historica de la conquista de la provincia de el Itzá* (1701). Jones consulted Villagutierre's accounts, as well as the original documents that he used, which provide ethnohistorical evidence for Itzá social and political organization.

The main historical source written by the Maya themselves that could be consulted when reconstructing the Maya account of the Colonial Period are *The Books of the Chilam Balam* (Farris, 1984). They record the histories of several diverse sociopolitical Maya lineage groups, as well as the Spanish presence in the Colonial Period (Jones, 1998; Cecil, 2009a). *Chilam* means spokesman, and *balam* translates as jaguar priest, which further translates as official k'atun prophet. (K'atuns are 20 year periods of the Maya calendar). *The Books* are indigenous histories that were originally recorded in hieroglyphs and passed along in oral form. They were written in Maya language using European script by Maya rulers and priests who were taught to read and write in Spanish (Rice, 2009).

Spanish Colonization of the Southern Lowlands

The first contact between Spaniards and indigenous populations in Mesoamerica occurred with the arrival of Hernan Cortes in 1519. The Aztec Empire, which dominated the region from central Mexico and Guatemala to Honduras, was overthrown within a couple years of their arrival (Charlton and Fournier Garcia, 1993; Jones, 1989; Palka, 2009). It was not until 1527 that colonization and missionization of the Yucatan and Maya Lowlands began. Longer still was the process of colonization and subjugation of indigenous groups in the southern Lowlands (Jones, 1989), or the southern frontier zone.

Due to the area's lack of commercially exploitable mineral resources, the fragmented (rather than highly centralized) nature of Maya political systems, and the dispersed nature of settlements, the process of conquest was not as swift as it had been for populations of central Mexico (Deagan, 2003; Farriss, 1984; Jones, 1989; Jones and Pendergast, 1991; Graham, 2011). Maya rebellions greatly impeded Spanish conquest of the frontier zone (Jones, 1998).

Cortes passed through Itzá territory and was close to Tipu as early as 1525 during his *entrada* into the eastern Lowlands. However, Cortes and his men were quickly driven out by the Itzá, which gained the Itzá the reputation of being hostile (Jones, 1998). This reputation, coupled with their remote location in relation to the major concentrations of Spanish colonization efforts in northern Yucatan, meant the Itzá and their allies (e.g. Tipu) were more protected from Spanish domination (Graham, 2011; Jones, 1998). In the early 16th century, regions of Spanish focus in southern Mesoamerica included what are now Guatemala, Honduras, Salvador, Nicaragua, Panama and Costa Rica because they had high commercial activity in precious metals, cacao and slaves. Belize and the Petén Lakes region of Guatemala were a relative backwater of the Spanish empire, as indicated by the fact that maps were very vague about Belize and its towns (Graham, 2011). Belize had no readily exploitable resources of interest to Spaniards, and was not even named until the late 16th to early 17th centuries (Graham, 2011). In addition, Belize's coastline was not accessible to large Spanish ships. There is a shallow coastal shelf and barrier reef away from shore, and mangrove forests dominate the shoreline (Graham, 2011). Pirates and privateers hostile to Spaniards also frequently occupied Belize's inlets, coastal lagoons, caves and atolls. In the middle of the 16th century Spaniards came to realize the profit of landholding and control of indigenous labor for inland Yucatan, but despite copious amounts of exploitable land and human labor, the factors described above deterred many from colonizing Belize (Graham, 2011).

In 1528, Francisco de Montejo's attempt at settlement in Chetumal, on the east coast of the Yucatan Peninsula, was also met with hostility and the Spanish retreated (Graham, 2011). It was not until after the establishment of primary colonial towns like Mérida, Campeche and Valladolid, and Alonso Pacheco's more aggressive *entrada* in

1543, that the first colonial town (Salamanca de Bacalar) (Figure 1.1) was established in what is now Belize (Graham, 2011). It is likely that Pacheco's *entrada* also involved the conquest and reduction of people surrounding Tipu, which was the center of the province the Spanish documented as Tz'ul Winikob' (alternately spelled Dzuluinicob above). Pacheco established cacao-based *encomiendas* in northern Belize and along the Belize River, however, Spanish control of them was tenuous. There were few Spaniards in the region and Maya rebellions began as early as 1547 (Jones, 1998).

Tipu was in the middle of a particularly rebellious territory. Although it was established as an *encomienda* in 1544, the Spanish did not have complete control of Tipu, or the surrounding frontier zone for many years. In response to constant Maya attacks on Bacalar, additional *entradas* were launched to re-conquer the southern Lowlands between 1567 and 1568 (Jones, 1998). The southern frontier came to be administered by the poor outpost at Bacalar. However, Spaniards there still lacked complete authority. They relied heavily on contraband coastal trading because they were inadequately supplied by both the Crown and the tribute payments of the few Maya communities that cooperated (Graham, 2011; Jones, 1998). Indirect contact with the Itzá and other unconquered groups for cacao, forest products, metal tools and cotton cloth was necessary for the town's survival (Jones, 1998).

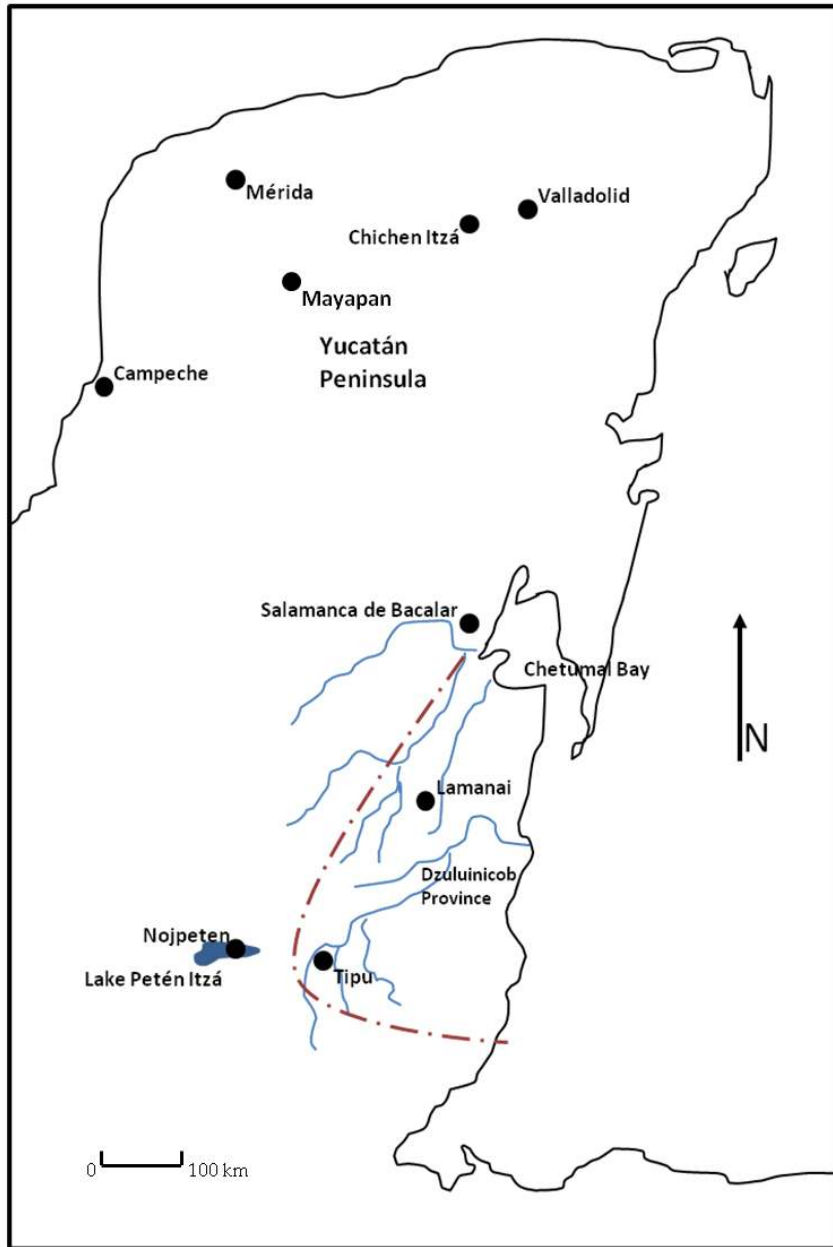


Figure 1.1: Map of Yucatan Peninsula and Study Region

It was not until the early 1600s that Spanish interest in the frontier zone was peaked, and their presence became more frequent. Worsened conditions in northern Yucatan *encomiendas*, caused by an increase in illegal *repartimientos*, or systems of forced labor, persuaded even more Maya to flee to the frontier zone. *Encomenderos*

experienced significant losses to their labor pool and tribute-paying populations, and the last unconquered kingdom of the Itzá Maya was targeted as the cause. Spanish bureaucrats and military decided that conquest and control of Nojpeten and the Itzá was the solution (Jones, 1998). Tipu was the last nominally Christian Maya town in the string of missions from Bacalar to Nojpeten (Graham, 2011; Jones, 1998) and provided a feasible pathway and base of operations for the conquest of the Itzá. The first attempts at conquest of the Petén region occurred between 1573 and 1580, but all were unsuccessful in even reaching the island of Nojpeten. It was not until 1616-1617 that Fray Juan de Orbita finally reached the island and started negotiations (Jones, 1998). In 1618, Orbita returned to the Petén with Fray Bartolome de Fuensalida via Tipu to continue attempts at missionization. However, evangelical attempts at gaining control of the Itzá were not sufficient. Nojpeten was not brought under Spanish control until 1697 when Spaniards resorted to military force (Jones, 1998). The years leading up to 1697 were characterized by frequent *entradas* met by armed Maya resistance.

The events outlined above illustrate that the social climate surrounding Tipu was quite hectic during the time that it was a mission town. Tipu became an *encomienda* in 1544 and a mission shortly after. Therefore, it was a community subordinate to both the Itzá and the Spanish, and it experienced firsthand the power struggle that occurred between Spaniards (both clergy and military) and surrounding Maya communities. After Fuensalida's failed attempt at bringing Christianity to the Itzá in 1619, Fuensalida returned to northern Yucatan and the Itzá began colonial efforts of their own, which meant attacks on Spaniards and any Maya communities who did nothing to resist them (Jones, 1998). The Itzá expanded their territory to the north, east and south of Petén Lake to create a buffer zone of indigenous communities willing to aid in resistance. In this way, the Itzá were able to end yet another attempt at the conquest of Nojpeten in 1622 by Captain Francisco de Mirones y Lezcano and Fray Diego Delgado. Tipu was "re-colonized" by the Itzá in the 1630s and people from other Belize mission settlements were forced to move there. In 1638 reports surfaced of mass desertions from Tipu, other interior towns, and even coastal villages. Coastal villagers claimed that Tipuans had told them to do so to avoid the wrath of the Itzá (Jones, 1998).

Fuensalida was sent back to Bacalar in 1641 on an unsuccessful mission to re-convert Maya rebels. On his way to Tipu he found only burned and deserted towns from Lamanai to the Belize River. His party of friars were captured, warned never to return and then released (Jones, 1998), so Spaniards avoided the region until the mid 1600s. In 1655, Francisco Perez, *alcalde* (town councilman) of Bacalar, compiled the census of Tipu (Scholes and Thompson, 1977) to convince the Spanish that the town was still a mission (Graham, 2011). This does not mean the frontier zone was more peaceful though. Perez went no farther than Tipu on his trip to collect census data because he feared attacks. Tipu was originally documented as containing 340 "souls" (Jones, 1989; 1998). In 1655 Perez reported 411 people (103 of whom were children) and all but 30 had Christian baptismal names. It is noteworthy that despite the social turmoil created by power struggles between the Itzá and Spaniards, the Maya at Tipu still conducted baptisms and bestowed Christian names (Graham, 2011). The other 30 individuals had Yucatec patronyms, which identified them as immigrants from northern Yucatan (Scholes and Thompson, 1977).

The reduction of Maya communities surrounding Tipu (by both Spaniards and the Itzá), frequent desertions, and immigration of Maya from northern Yucatan means the population was in flux during the Colonial Period. While 411 may be an accurate population estimate for 1655, it was an inaccurate reflection of the town's population throughout the Colonial Period (Jones, 1989). Of the 411 names on the census, 314 were residents of Tipu and 97 moved to Tipu from nine other surrounding towns after a rebellion in 1637. The 97 immigrants were likely those forced to move to Tipu by Itzá reduction efforts (Jones, 1998). In 1678, Sergeant Major Antonio de Porrás was sent to regain contact with Tipu and a supposedly voluntary reduction of Tipu and 600 baptisms were the result (Jones, 1998). Other documents suggest the *entrada* was actually a violent one and reduction was forced (Patch, 1993). In either case, it seems that the "re-reduction" of Tipu by the Spanish in 1678 greatly increased the population.

The final take-over of the Itzá was set into motion in 1692 by Basque aristocrat Martín de Ursua y Arizmendi, who used the construction of the Camino Real from Mérida to Guatemalan territory as a disguise for another *entrada* on Nojpeten and the

Lakandon Maya (Jones, 1998). Native resistance made the first and several subsequent *entradas* unsuccessful, but Ursua finally captured Nojpeten in 1697. Meanwhile, Captain Francisco Hariza y Arruyo appointed Tipu's town council and sent them to Mérida to confirm their positions, claiming that he had solidified Tipu's loyalty to the Crown (Jones, 1998). However, Ursua's control of Nojpeten was tenuous. He and his men were surrounded by hostile Maya groups who would not succumb to missionization efforts. Food supplies ran low because Spanish supply lines were frequently ambushed. Although some reinforcements arrived in 1698, they did not have enough supplies to continue habitation of Nojpeten (Jones, 1998). Epidemics were frequent on the island. One documented in 1699 also affected surrounding indigenous populations, which likely included Tipu (Jones, 1998). Conflict between Spaniards and Maya in the Petén regions continued into the early 1700s. In 1709, the Petén was finally under the complete governance of the Audencia of Guatemala. The entire population of Tipu was forced to move to a settlement near Nojpeten in 1707 (Jones, 1998).

Christianity in Belize

Given this tumultuous history, Tipu's close ties with the Itzá, and long periods of Spanish absence in Belize, it is remarkable that Christian ritual was upheld throughout the Colonial Period and has persisted in Maya communities to this day (Graham, 1998). Spanish priests often reported that the Maya rejected the Christian God and continued to be idolaters when left "unsupervised." Historians and archaeologists have largely accepted such statements (Graham, 2011). As a result, many have assumed that the adoption of Christianity by the Maya was simply a way to satisfy the Spanish and disguise the continued practice of pre-contact ritual (Farriss, 1984; Graham, 2011). However, archaeological evidence at both Tipu and Lamanai for continual use of church structures and adherence to European Catholic burial custom, despite rebellions and long periods of Spanish absence, has forced archaeologists to re-think the assumption (Graham, 1998; 2011). Elizabeth Graham (2011) describes how the Maya did not act only to resist ideas brought by Spaniards, they analyzed, intellectualized and appropriated their

religious ideas. While the Maya may have resisted Spanish civil authority (e.g. Wrobel, 2012a), they came to consider themselves Christian and remained so because it had become their way of life (Graham, 2011). Nancy Farriss (1984:9) initially pointed out this phenomenon, stating that Maya culture "was transformed by Spanish influence but along Maya lines and in accordance with Maya principles."

Several factors facilitated the adoption and persistence of Christianity in Belize. They include: the relatively less intrusive nature of the region's initial colonization, the manner in which Christianity was presented, and the existing worldviews of the Maya. Communities were not immediately uprooted and forced into a physically demanding lifestyle that involved mandatory acceptance and practice of a completely alien religion. Therefore, Christianity was not attached to an oppressive, completely unreasonable foreign authority (Deagan, 2003; Graham, 2011).

Encomiendas lasted for over a century in Belize, but tribute demands for products and labor were not very different from those of pre-contact elites (Farriss, 1984; Graham, 1998; 2011; Jones, 1998). Pre-contact hierarchies in frontier zone missions were also largely left intact because it was easier to extract tribute from communities via the leaders who already had authority (Carmack, 1991; Farriss, 1984; Graham, 1998; Jones, 1989; 1998; Restall, 1992; Roys, 1943). Restall (1992) suggests the *cah* formed the basis for organization of *encomiendas*. In other words, Maya lifestyles were not completely transformed because the labor required for tribute production and their governing structures remained consistent. Existing Maya elites simply answered to a new, higher authority and transferred part of the tribute they appropriated to the Spanish (Farriss, 1984).

Christianity was imposed upon colonized Maya communities, but they were not necessarily forced to abandon all their religious beliefs. Graham (1991; 2011) suggests that there were many parallels between Maya religious belief and Christianity that made Christianity operationally similar and therefore "easier" to adopt. Even though Christianity is a monotheistic religion, the incorporation of saints that represent divine figures more accessible to followers was likely seen as similar to the polytheism of Maya religion. Saints were easily conflated into the deities of indigenous religion. Rituals

performed by friars (carrying effigies, keeping statues of saints in their houses, burning candles, and kneeling in front of images to pray) also were not completely foreign actions (Graham, 2011).

The Spanish were also effective at indoctrination. In some cases, Maya individuals were put through Franciscan schools so that they could teach Christianity, carry out ritual and supervise its practice while friars were absent. These individuals were given the title of *maestros cantores* (Farriss, 1984; Graham, 2011) and likely had great authority as established members of a community. Another effective method friars used to instill Christianity was to focus on the indoctrination of children (Graham, 2011). There were very few grave goods among the burials associated with the church structure at Tipu. However, of the 23 burials that contained Venetian glass beads from necklaces or bracelets, 16 were juveniles (Graham, 2011; Smith et al., 1994). Graham (2011) suggests that this is because friars gave such artifacts to children as rewards for learning the catechism. Before contact, artifacts were rarely included in juvenile burials.

Yet another factor that may have contributed to the acceptance and persistence of Christianity is the cyclical view of time held by the Maya (Farriss, 1984; Vail, 2009). Farriss (1984) suggests that they saw Spanish conquest in general as a repetition of history from which they would eventually be delivered when Spanish rule inevitably ended (Vail, 2009). The Maya held that good and bad times begin, end, and are repeated again, and in the *Chilam Balam* Spanish rule was prophesized as one of several evils that the Maya would experience (Farriss, 1984; Vail, 2009). It is unclear whether the Maya viewed the religious impositions of the Spanish in the same way as their social and political impositions, and therefore whether Christianity was seen as a means for control and something to be simply be endured. However, even if acceptance of Christianity was a means of cooperation to make Spanish occupation tolerable, it still contributed to the religion's persistence in the Lowlands.

Graham (2011) suggests that the missionization of Belize by Franciscans also facilitated the adoption of Christianity (Deagan, 2003). The Mendicant orders that were granted the authority to Christianize Mesoamerica included the Franciscans, Dominicans and Mercederians. Of the three, Franciscans were most dedicated to bringing Christianity

to regions that others avoided (Graham, 2011), which meant they were first to colonize Belize. They were preachers who denied the reformist efforts begun in Spain prior to their colonization of the Americas. In response to the church's laxity and excess of wealth, they rejected institutionalization and sought autonomy from Spanish civil authority (Graham, 2011). They promoted the ideal of Gospel simplicity and living a life of poverty. Their aim was to regain the spiritual purity of the early church and return to the evangelizing mission. As part of the Mendicant orders, they took vows of poverty and vows that forbade them to own property in common (Graham, 2011). Therefore, even though they were required to exact tribute from a community, they were focused on creating urban missions in any region that "needed" them. The desire of Franciscans to spread the Gospel independent from the authority of the Crown led to the creation of mission communities that also valued independence (Graham, 2011). In contrast, the goals of secular clergy were heavily influenced by the desires of Spanish colonists to dominate Mesoamerican communities through economic gain (Graham, 2011).

Given the more peaceful nature of initial missionization by Franciscans (Deagan, 2003) and their greater autonomy from the Crown, the Maya at Tipu were presented with new religious views that were not necessarily associated with the aggressive colonization efforts of Spaniards in northern Yucatan. Therefore, taking on new religious views may not have been thought of as subjugation, especially since systems of governance, trade with the Itzá and coastal communities, and required tribute remained consistent. It was not until 1582 that secular clergy were given preferential treatment by Spaniards and the influence of regular clergy (i.e. the Franciscans) diminished (Graham, 2011; Jones, 1998). Regular clergy were seen as a hindrance to tribute extraction and were therefore not the ones the Crown wanted leading colonization efforts (Graham, 2011). However, by the time the Spanish moved their focus to colonization of the frontier zone in the early 1600s, and the influence of Franciscans finally diminished in Belize in the mid 1600s, Christianity had been practiced at Tipu for over 60 years and was very much a part of Maya life.

The Archaeological Record

The historical record of Spanish colonization in the Maya Lowlands provides a detailed timeline of events that shaped the colonial outcomes at Tipu. However, social, political and/or cultural changes that occurred within the Tipu community remain ill-defined. The archaeological record of Tipu contributes to our knowledge of the colonial encounter there by providing both artifacts and human remains that illuminate daily life with information that is independent of the historical record (Stein, 2005). As mentioned above, it was the archaeological records of missionization at Tipu and Lamanai that inspired the rethinking of our assumptions about Maya acceptance of Christianity (Graham, 2011). When historical, archaeological, and bioarchaeological records are considered together, a more complete picture of Tipu as a Spanish mission emerges. Overall, the archaeological record supports the idea that aside from the adoption of Christianity, lifeways of the Tipu Maya did not change drastically with colonization.

Excavations at Tipu have focused on the church structure and associated cemetery, which is why the site is most well known for its Colonial Period occupation and the evidence it holds for the effects of Spanish contact (Graham et al., 1985; 1989; Graham, 1991). Complex I, to the southeast of the church, is the only pre-contact feature excavated (Cecil, 2009b; Graham, 2011). It was built and remodeled during the Terminal Classic and early Postclassic. Its architecture and associated artifacts confirm the pre-contact community's close ties to the eastern Petén Lakes region and connections with northern Yucatan (Cecil, 2009b; Graham, 2011). Elaborate platforms and temple types at Complex I were first defined at Mayapan and have also been documented at Campeche, Cozumel, and Tapoxte Island (Cecil, 2009b). In addition to Kowoj style pottery, Spanish made vessels were also recovered from areas with Postclassic components, which indicates continued use of those areas during the Colonial Period (Cecil, 2009b; Cohen et al., 1994a; Graham et al., 1985). Construction of the church in the early 17th century marked the inclusion of Tipu in the Spanish *encomienda* and mission system (Cecil, 2009b; Jacobi, 2000; Graham, 2011).

In addition to continued use of Postclassic structures and ritual spaces, trade goods and ceramics suggest Tipu remained part of the un-colonized Itzá Maya economic sphere and maintained pre-contact subsistence strategies throughout the Colonial Period (Cohen et al., 1994a; Emery, 1999; Graham et al., 1985; Graham, 1991; 2011; Jones, 1982). There were no changes in slips, paints or general vessel appearance of locally produced pottery, no changes in lithic technology (Graham, 2011), and despite introduction of some metal tools by Spaniards, they never dominate assemblages (Graham, 1991). Faunal assemblages indicate a continuous, highly generalized use of a variety of animal species from all available ecosystems from the Postclassic through the Colonial Period (Emery, 1999), and continued trade with coastal communities for marine resources (Graham, 1991). Milpa farming was continually used to grow corn, squash, beans, chiles, sugar cane, and plantains. Production of cacao persisted because it remained a valuable commodity (Graham, 1998; Jones, 1982). Cacao was the economic base of pre-contact Tipu elites and accepted as tribute by the Spanish (Jones, 1982; Graham et al., 1985). Documents written by Spanish friars indicate corn milpas were harvested two or three times per year, which suggests intensive cultivation during the Colonial Period (Jones, 1982). However, this intensity of cultivation is also documented among contemporary populations and was likely normal practice in pre-contact times to offset the danger of crop failure due to floods or unpredictable rainfall (Jones, 1982). The archaeological record holds no evidence for the emergence of commodity production with Spanish colonization at Tipu (Graham, 1998).

The remnants of the church at Tipu were first located and exposed by Grant Jones, David Pendergast, Robert Kautz and Claude Belanger in 1980 (Graham, 2011). Subsequent fieldwork between 1984 and 1987 by Mark Cohen and Elizabeth Graham resulted in further definition of structures surrounding the church and the excavation of 585 historic period burials (176 males, 119 females, 249 juveniles, and 49 adults of unknown sex) within the walls of the church structure and outside the walls to the north, west and south (Graham, 2011; Jacobi, 2000). Tipu's church, often called a *ramada* (open) chapel, is close to the Macal River, on its west bank, above the modern floodplain. It is 23m long and 8m wide, with apsidal east and west ends, and 80cm thick walls that

were plastered (Graham, 2011) (Figures 3.2 and 3.3, Chapter 3). Except for around the altar, where stone walls reached the ceiling, the north, south and west walls were likely about 1.5m high (Graham, 2011). The upper half of the church was made of a wood frame and thatched roof (Jacobi, 2000). The architectural style of the church is typical of mid 16th century church constructions elsewhere in Americas (Jacobi, 2000; Graham, 1998; 2011; Saunders, 1990). The church's interior included a nave, simple sanctuary and sacristy. The nave is where followers congregated for services, the sanctuary is the landing at the east of the church where the altar was placed, and the sacristy is a separate room where ritual items were stored and friars prepared for mass (Graham, 2011).

In addition to the church, a rectangular plaza and several other Colonial Period structures that incorporated foundations of Late-Postclassic buildings were built on top of debris from Postclassic occupations to form the new center of the mission town (Graham, 1991; 2011). To the north of the church structure, there was an *atrio* (courtyard) and the foundation of a rectory (residence for visiting friars) (Graham, 2011). The majority of individuals buried at Tipu were likely interred in and around the church structure continuously from the establishment of the mission in 1544 to at least 1638, when a major rebellion forced temporary abandonment and possibly the destruction of the church (Graham et al., 1989; Graham, 2011). However, evidence that the northern *atrio* was disturbed for later burials, after the church and its associated buildings had collapsed, indicates Tipuans continued using the cemetery throughout the 17th century (Graham, 2011), perhaps until the community was forcibly removed in the early 1700s (Graham, 2011; Jones, 1989).

European Catholic tradition dictated that individuals of higher status be buried inside the church walls, and those of highest status were buried closest to the altar; people of lower status were buried outside the church walls (Miller and Farriss, 1979; Muller-Wille, 1993). Regardless of status, all individuals were to be buried with their heads to the west and feet to the east (Jacobi, 2000; Jones, 1989; Miller and Farriss, 1979; Muller-Wille, 1993). At Tipu, males, females and juveniles were buried both inside the church walls (in what would have been the floor of the church) and outside. All but a few individuals were buried in the "proper" orientation with their heads toward the west

(Graham et al., 1989; Jacobi, 2000). Both inside and outside the church walls, some commingling of human remains occurred when previous burials were disturbed to make room for new burials. Disturbance is most pronounced at the back of the church inside the walls. The burials that were lined up along the altar exhibited the least amount of commingling (Jacobi, 2000).

Artifacts

The majority of interments at Tipu had no associated burial goods, which is typical of Christian burials (Graham et al., 1989). Burials that did include grave goods were sporadically located both inside and outside the church walls, so the presence of burial goods does not seem to correlate with an individual's social status. The majority of artifacts that were associated with burials include jewelry and shroud pins (Jacobi, 2000). Jewelry styles include: pendants, silver earrings, glass bead necklaces and bracelets, objects of jet and amber, and other jewelry locally made from *Spondylus* shells and dogs' teeth (Graham, 2011). Only a few coffins were present, one of which was associated with an additional small wooden chest, evidenced by remnants of an iron lock plate (Graham, 2011). As mentioned previously, the majority of glass beads were associated with juvenile burials (Smith et al., 1994).

Historical records indicate that on every visit to a mission, friars would bring a small, locked, wooden chest and *ara* (table or slab consecrated by a bishop) with them. The *ara* was placed on the altar of the sanctuary, and the wooden chest contained the chalice and other liturgical paraphernalia required for church services (Graham, 2011). In addition to the one chest that was included with the coffin burial, similar iron lock plates were found in association with the rectory. Olive jar sherds, a copper ring and glass beads were also recovered in residential structures surrounding the church (Graham, 2011).

Skeletal Analyses

Initial analyses of the human remains excavated (Cohen et al., 1989; 1994b; Danforth et al., 1997; Jacobi, 2000) are indicative of a relatively homogenous burial sample in terms of skeletal health, stature, and genetic variation (determined from dental morphological variation). However, this does not imply that Tipu's population was isolated or static. The historical record indicates the population was in flux due to arrivals of immigrants from northern Yucatan, intermarriage with the Itzá, reduction events by both Spaniards and the Itzá, and desertions during times of violent rebellions. Dental metrics and non-metric traits are indicative of a relatively genetically homogenous population (Jacobi, 2000). There is no evidence of Spanish admixture among the indigenous Maya burial sample, and no Europeans were buried in or around the church. While most individuals were buried in simple shrouds, the few that were buried in coffins near the altar also have dental characteristics typical of native Central Americans (Jacobi, 2000).

The skeletal sample at Tipu exhibits low prevalence of chronic infections, nutritional deficiencies, and trauma due to interpersonal violence (Danforth et al., 1997; Jacobi, 2000). Average age at death for adults (determined from osteological age indicators) was 28.5 years (Danforth et al., 1997), so Tipu represents a relatively "young" burial sample. These pieces of evidence could suggest that epidemics caused sudden death without producing skeletal signatures of illness. No mass graves are evident, so there is no evidence of epidemic, large-scale mortality (Jacobi, 2000). Colonial documents and census data from 1618 to 1697 do suggest dramatic population fluctuations in a time period contemporary with disease outbreaks, and population reductions were likely influenced by disease epidemics that killed susceptible individuals rapidly (Graham et al., 1989; Jacobi, 2000). However, it is important to keep in mind that reported fluctuations in Tipu's population were also influenced by: 1) inaccuracy of historical records due to sporadic Spanish presence, 2) influxes of Maya who were fleeing Spanish colonization efforts in northern Yucatan, and 3) the tendency of indigenous people to abandon even the least heavily controlled missionized towns for uncolonized regions of the frontier zone during times of social upheaval and rebellions

(Farriss, 1984; Jones, 1998). In 1618, census records indicate the population of Tipu was 340 (Jones, 1989). In 1622, the population dropped to 30, but the very next year it was back to 340, and 20 years later the population was 1100 (Jones, 1989). It is uncertain whether the very low population in 1622 was due to an epidemic or whether it reflects inaccuracy in census documents or a dispersal event.

In relation to Maya communities that were forcibly relocated by reduction efforts and therefore under direct Spanish control (e.g. Lamanai), population size and health at Tipu was relatively well maintained (Danforth et al., 1997; Jacobi, 2000). In fact, the health and stature data from the Tipu burial sample are very similar to that of the pre-contact Petén Maya. Along with low incidence of anemia, this attests to Tipu's lower population size, and higher degree of isolation (Danforth et al., 1997). Nevertheless, it is important to keep in mind that Tipu was not a closed population (Danforth et al., 1997).

Studies that have compared the skeletal "health" of individuals buried inside the church structure to those buried outside, have also come to the conclusion that there were no major health differences between the burial locations, and therefore no evidence of differential health based on social status. Skeletal signatures of nutritional deficiencies or illness (e.g. porotic hyperostosis) and stature do not vary significantly between individuals buried inside and outside the church walls (Cohen et al., 1989; 1994b; Jacobi, 2000), and general long bone robusticity is relatively homogenous among the burial groups at Tipu (Cohen et al., 1989; Wrobel, 2003). Therefore, in addition to lack of differentiation by health indicators, there is no drastic variation in body size among burial groups at Tipu that may be indicative of differential health or nutrition.

The historical and archaeological records detailed thus far highlight the unique case study that Tipu presents and its potential for adding to our understanding of the process and outcomes of Spanish colonization in the Americas. Both lines of evidence suggest that lifeways did not change drastically for the Tipu Maya, except for their apparently complete acceptance of Christianity. However, it seems unreasonable that missionization and conversion to Christianity were events that had no other societal consequences. Even though the structure of Christianity was not drastically different from pre-contact Maya religious beliefs, the acceptance of a foreign religion in a region caught

in the middle of power struggles between the last unconquered Maya kingdom and the Spanish had to inspire some cultural changes.

Human osteological evidence for homogeneity in health regardless of burial location at Tipu suggests that the highly stratified social structure of pre-contact times was in fact drastically changed. However, it must also be considered that while human osteological indicators of "health" and diet can be indicative of social status (Cucina and Tiesler, 2003; 2007; Somerville et al., 2013; White et al., 1993), they are not necessarily so in all cases (Powell, 1992; Robb et al., 2001; Silverman, 2002). This is because absence of skeletal evidence of disease or malnutrition does not necessarily mean an individual was "healthy" (Wood et al., 1992). Tipu could represent an instance in which skeletal health indicators are not representative of an individual's status in the first place.

In any case, this study provides another line of evidence for investigating Colonial Period Maya social stratification. As an investigation of the distribution of labor that is evident from the human remains interred at Tipu, this study will contribute to our understanding of social impacts of missionization. While it will not illuminate all the societal consequences that accompanied the acceptance of Christianity, it will aid in identifying societal changes that the Maya chose to make.

Theoretical Perspectives

As a bioarchaeological investigation of the effects of colonization on Maya social structure, this research draws on several different sources of information: historical, archaeological and human osteological. Therefore, several bodies of theory underlie the formation of research questions and the interpretation of results presented in the following chapters. Theory concerning the nature of colonial interaction and its effects on cultural outcomes is discussed to stress the importance of considering each historically and archaeologically defined colonial encounter holistically and individually (Farriss, 1984; Gasco, 2005; Rogers, 2005; Spicer, 1961; Stein, 2005). The overarching theoretical perspective employed is the biocultural approach (Armelagos, 2008) with an emphasis on interpreting skeletal evidence of labor as influenced by social organization. By extension,

skeletal signatures of activity are expected to reflect any changes in Maya social structure that accompanied the establishment of Tipu as a *visita* mission. Bone functional adaptation is discussed because it is the primary principle of any study that uses bone morphology to make inferences about the activity patterns of a past population.

Colonization

The archaeology of colonization is essentially the application of historical archaeology to any site where different cultures were brought into contact by colonial efforts (Stein, 2005). Research focuses on the archaeological evidence of cultural changes that contact produced (Spicer, 1961; Van Buren, 2010). As a study of colonial archaeology, this study follows two theoretical perspectives that were developed in the 1990s and have transformed the field of historical archaeology (Silliman, 2004; Van Buren, 2010). One involves studying culture change with a holistic understanding of the people interacting in a colonial situation. This entails knowledge of the existing social structures of both the colonizers and the colonized and the way that power struggles both within and between cultures often leads to the production of new social and cultural identities (Bourdieu, 1977; Giddens, 1984; Silliman, 2001a; Stein, 2005; Van Buren, 2010). The second perspective employed is a "bottom-up" understanding of colonialism that emphasizes the collective agency of the people being colonized and how they, in part, determined the variety of colonial outcomes that followed European expansion (Hall and Silliman, 2006; Silliman, 2004; Stein, 2005; Van Buren, 2010; Wolf, 1982). Both theoretical approaches involve an emphasis on contextualizing "the highly variable ways in which people negotiated, embraced, resisted, and were transformed by their incorporation into a new world order." (Van Buren, 2010: 152). In this section, the first principle is discussed in terms of an Interregional Interaction Network (IIN) (Stein, 2005) (defined below), with a brief description of Tipu's IIN. The second principle is illustrated by the concept of missionization (Van Buren, 2010) and the implications that the archaeological record of Tipu holds for the investigation of how an instance of Spanish imposition of Christianity was negotiated by the Maya.

A predominant goal of historical archaeologists studying the varied results of European colonialism in the Americas has been to gain a better understanding of the colonization process as it has occurred cross-culturally throughout human history (Gasco, 2005). One general principle that emerges from archaeological and historical studies of colonialism is that the nature of the interplay between two societies brought into contact by colonization efforts, and the societal end results, depended on many different factors encompassed within a given location and time period (Farriss, 1984; Gasco, 2005; Rogers, 2005; Spicer, 1961). Gasco (2005) cites several factors that shape colonial life. Aside from the objectives of colonizers (e.g. the resources they targeted for exploitation), these factors involved the degree to which indigenous and intrusive populations varied in cultural histories, technological traditions, economic systems, systems of social stratification, and ideological and religious systems.

The political, economic and social systems of Spain and Mesoamerica were structurally similar in many ways: both had rigidly hierarchical social systems controlled by hereditary nobility, both organized settlement systems to reflect such hierarchy, and both had economic systems based on long-distance exchange, markets, and systems of taxation or tribute (Gasco, 2005). However, many other cultural and environmental factors contributed to the great variation in Mesoamerican outcomes of Spanish contact and colonization (Gasco, 2005; Spicer, 1961). The varied environments of the Maya Lowlands and the consequent time and effort the Spanish invested at any particular mission led to very different outcomes throughout the region. Therefore, it is impossible to create one generalized story for Spanish conquest of the Maya. A site-by-site examination of the cultural outcomes of Spanish rule is more appropriate and allows for better-informed comparisons when research questions are expanded to interregional investigations of colonization events.

For example, the archaeological record at Lamanai, which is the only other site in Belize known to have a mission church established during Spanish colonization (Graham, 2011), presents a very different picture of the Spanish colonial encounter where changes to Maya lifeways were more pronounced. The Maya buried in the context of the church at Lamanai had a higher prevalence of skeletal evidence for disease and/or malnutrition than

Tipuans (Danforth et al., 1997). The faunal record also indicates a decrease in the diversity of species exploited for subsistence in the Colonial Period, which was not seen at Tipu (Graham, 2011). Graham (2011) suggests that these differences in the cultural effects of colonial encounters at Tipu and Lamanai are due to Lamanai's proximity to Bacalar and its larger population. The Maya at Lamanai experienced a more intrusive occupation because they were closer to an established Spanish outpost, which meant more pronounced lifestyle changes and health impacts than those experienced by the Maya at nearby Tipu. It is likely that this also meant a difference in community dynamics between the two missions (Graham, 2011), despite their proximity to one another and their roles as integral links in the trade network that connected the Petén region and coastal trade routes.

This is not to imply that each site (colony or mission) existed in isolation. Instead, the archaeological and human biological signatures of colonization are considered within the context of the interactions between the colonizers and the colonized. Stein (2005) refers to this as an Interregional Interaction Network (IIN), and a key to understanding any colonial encounter. An IIN is composed of the indigenous population being colonized, the mission village or colony where colonization occurs, and the colonizers. Understanding the pre-colonial social backgrounds of both the colonizers and the colonized, and the nature of their power relations, is crucial to understanding the outcomes of colonization observed at a site because it allows consideration of both the regional and interregional contexts of a colonial encounter (Lightfoot, 2005; Stein, 2005). The colony represents the regional context and the social backgrounds of the colonizers and the colonized represent the interregional context. Each culture involved in an IIN is composed of various groups whose interests, goals and social strategies are often in conflict. The outcomes of culture contact are influenced by both the intra-cultural power relations of the colonizing and colonized populations, and the inter-cultural power relations between the two. The cooperation and competition among the three (or more) nodes of an IIN define its organization, and the end result of their interaction is a factor of the patterned variability in power relations of the societies involved (Stein, 2005). In sum, it is necessary to develop a holistic understanding of colonial encounters in order to

understand their nuances, and to make future comparative analyses effective (Stein, 2005).

The archaeological and historical records of Tipu indicate that it was a village located in the middle of interactions among three socio-political spheres: that of the community at Tipu, the Spanish, and the Itzá (Cecil, 2009b). This IIN influenced the creation of the archaeological record at Tipu, and is therefore an underlying consideration of interpretations made in Chapters 3 and 4 of this dissertation. As outlined in the historical background section above, the social climate of Tipu was influenced by power struggles between the Itzá and Spanish, but also by the intra-cultural conflicts between Spaniards representing the Crown and Franciscan missionaries, and between the Itzá and surrounding Maya communities. It was these inter- and intra-cultural conflicts and interactions that influenced the colonial encounter at Tipu, and it was in the midst of these interactions that the archaeological record of Tipu was created.

Missionization and Collective Agency

Missionization refers to a situation where natives and Spaniards "negotiated the evangelical and acculturative programs instituted at formal missions" (Van Buren, 2010:159). It is a situation that represents directed culture change (Spicer, 1961), in which natives were forced to accept and practice specific programs of cultural reform, while also re-examining their established beliefs and traditions (Graham, 1998; Hanson, 1995). The archaeological record of mission sites can therefore provide clues about how indigenous belief systems were transformed (Andrews, 1991; Graham, 1998). At Tipu, the archaeological results of missionization were the remnants of a church and associated burials that conformed to European Catholic tradition (Miller and Farriss, 1979; Muller-Wille, 1993). The continual interment of individuals by the community, despite rebellions and the influence of the un-colonized Itzá, indicates Christianity (however it was viewed) had become daily practice, and therefore structured society and lifestyles (Graham, 1998; 2011).

We can never really know what exactly the Maya at Tipu came to believe, but it is clear that Christianity became the dominant religion and has persisted to this day (Graham, 2011). In this way, Tipu exemplifies the idea of collective agency (Silliman, 2004). Agency is the principle that the colonized members of a society act with purpose, despite the presence of a dominant colonizing force (Silliman, 2004). Underlying this principle is the idea that culture is shaped through the routine performance of socially sanctioned, daily activities. Culture can also be modified by the same process when people decide, or are forced, to change their activities under a set of new conditions (Bourdieu, 1977; Giddens, 1984). It is the daily activities of people and changes therein that create observable changes in the archaeological record (Bourdieu, 1977; Giddens, 1984; Given, 2004; Hall and Silliman, 2006; Stein, 2005). Tipu represents a site where the daily lives of indigenous Maya were changed by missionization. However, Christianity was not simply an imposition that they accepted in order to appease Spanish friars (Graham, 2011). The persistent use of the church and maintenance of European Catholic burial customs can only be seen as a conscious, collective choice to adopt Christianity because these actions continued throughout long periods of Spanish absence (Farriss, 1984; Graham, 2011; Lightfoot et al., 1998; Van Buren, 2010).

The Study of Social Change through Labor

While the most prominent expression of collective agency at Tipu is the acceptance and persistence of Christianity, the burial sample presents other avenues for investigating societal changes, driven by the Maya, that occurred within the context of missionization. The aim of this study is to investigate Colonial Period social structure at Tipu using skeletal evidence of how labor was distributed among individuals of different burial locations (Silliman, 2004). Archaeologists essentially study past peoples and their social relations as they are objectified by the labor process, since it is through labor and human actions that culture and ideas are made material (McGuire, 2006). In the context of historical archaeology, "labor is what is colonized, enforced, controlled, exploited, indebted, hierarchical, unequally distributed, often rigidly structured and simultaneously

global and local" (Silliman, 2006:147). Silliman (2001b; 2004; 2006) argues that we cannot discuss indigenous cultural traits in colonial settlements without understanding the labor regime that regularly engaged bodies and influenced interpersonal relationships and a group's material culture. While Silliman did not indicate that this understanding also involves human skeletal evidence of labor, his statement effectively describes the goal of this dissertation, and particular emphasis is placed on "understanding the labor regime that regularly engaged bodies."

It should be noted that many historical archaeology studies examine colonial encounters through archaeological evidence of imposed labor systems and the impacts forced labor had on society (e.g. at plantations, work camps, and sites in industrial contexts) (Silliman, 2006). Bioarchaeological studies also document skeletal signatures of increased labor demands that accompanied Spanish colonization (e.g. Larsen and Ruff, 1994; Larsen et al., 1996, 2001; Ruff and Larsen, 1990). However, labor was not "forced" on Tipuans. Their subsistence strategies and tribute requirements remained consistent and tribute demands did not lead to any intensified production (Emery, 1999; Graham, 1998). Therefore, a new labor regime was not a source of change. Rather than examining how a colonial regime influenced the labor requirements of a group, this study uses skeletal evidence of the types of labor people engaged in to examine the nature of Tipu's social structure.

Here, skeletal indicators of labor are treated as signatures of individuals' daily activities that are guided by their place in society. The use of labor distribution to discuss social hierarchy inherently employs Marxist theory because Marx and Engels (1962) emphasized human labor as the basis for social relationships within human groups (Marx and Engels, 1962; McGuire, 2006). Labor is a necessary part of human existence because human energy is required to manipulate nature and extract the resources we need to survive (Marx and Engels, 1962). However, labor is not simply work nor simply reflective of economics; it is a conscious action and involves social relationships, individuals, and the tools they create to perform daily tasks for their own subsistence and for the rest of society (Lawrence and Shepherd, 2006; Marx and Engels, 1962; McGuire, 2006; Silliman, 2001b; 2004; 2006). In other words, labor does not only involve people

and the tools and techniques they employ to do certain tasks, it involves society as a whole in that work must be organized, tasks distributed among individuals, and surplus products distributed to the whole of society. Labor power is what drives production and subsistence strategies. It serves as a basis for social interactions so it is also a foundation for political forms and ideology (McGuire, 2006). This is not to imply that labor and the interactions that go along with it are the *causes* of a society's system of governance, but as part of the interconnected whole of society, they influence and are reflective of how a society is organized.

The burial sample at Tipu represents a group of people relying on the same subsistence strategy, and it is thought to represent how they organized the work required for that strategy among the community. The hierarchy that is implied by burial locations at Tipu (Parker Pearson, 1999) is seen as a potential "map" of society where burial groups can be separated by the kinds of labor each segment of society engaged in. For instance, the burial groups inside the church near the altar presumably represent community leaders who would have primarily done administrative tasks, and lower status individuals buried outside the church walls would have done more manual labor associated with hunting, gathering and farming. At the same time, it is also possible that the segment of society that accepted indoctrination into the church did not involve such task specialization according to social status. In some cases, colonization led to the deposition of indigenous rulers and allowed individuals of lower status to assume leadership roles (Farriss, 1984; Sahlins, 1985). As mentioned above, bioarchaeological and archaeological studies to date that document homogeneity in status indicators among the Tipu burial sample tend to support this latter scenario (Cohen et al., 1994b; Danforth et al., 1997; Jacobi, 2000; Wrobel, 2003).

Biology and Culture

Franz Boas was the first anthropologist to apply the work of German anatomists like Rudolf Virchow (1872) and Julius Wolff (1892) to studying culture from the perspective of the human skeleton (rather than only focusing on racial descent) because

he saw the human body as subject to environmental influence (Pearson and Buikstra, 2006; Sofaer, 2006). He inspired the investigation of human behavior through population-level investigations of health, disease, and the biological effects of environmental stress, with an underlying evolutionary perspective (Sofaer, 2006). This has led physical anthropologists to explore just how much can be said about a past population when the biological effects of human behavior, in its broadest sense, are known. Examples include: using human genetic and phenotypic variation to investigate migration patterns at global and regional levels (e.g. Steele and Powell, 1994), evaluating the impacts of subsistence strategies on health and nutritional status, and investigating the effects that daily life (e.g. activity patterns) have on the body (e.g. Angel, 1952; Bridges, 1997; Hawkey and Merbs, 1995; Hooton, 1930; Jurmain, 1999; Larsen et al., 1995; Ruff et al., 1984). The study of labor distribution at Tipu from the perspective of the site's human skeletal sample is made possible by the skeleton's predictable adaptations to biomechanical forces.

The human skeleton can record aspects of past lifeways that would not otherwise be apparent historically or archaeologically (Boyd, 1996; Houston et al., 2006; Larsen, 2002). J. Lawrence Angel was one of the first to describe how biomechanical forces affect the skeleton and how such skeletal signatures could reflect past behavior. (Angel, 1952; Pearson and Buikstra, 2006). The theoretical revolution of New Archaeology and processualism in the 1960s and 70s marked the beginning of considering the human body as a unit of archaeological analysis (Sofaer, 2006). Just as Middle-range theory combined ethnographic observations and artifacts to derive more information from archaeological sites (Binford, 1972), the value of human remains as "artifacts" was realized as a way to study otherwise unobservable past behaviors (e.g. ritual and belief) (Parker Pearson, 1999; Sofaer, 2006). Middle-range theory essentially uses "the known" to explain what is unknown. Ethnographic observations of how artifacts are produced and then distributed at a habitation site represent known behavior, and are used to interpret the archaeological record for behavior that is unknown. Human remains present yet another avenue for Middle-range theory and therefore archaeological investigations. Bioarchaeologists use what is known from studies of contemporary populations about the biological effects of

age, sex, diet, disease, and activity on the skeleton to interpret behavior in past populations. From the 1990s onward, bioarchaeologists have pursued the investigation of behavior's effects on biology from the perspective of the human skeleton (Pearson and Buikstra, 2006; Sofaer, 2006), with the added information that archaeological context can provide. Much can be said about a population from skeletal health indicators, age and sex profiles, and incidences of disease and trauma. However, the interment of bodies by members of a society means that the placement of human skeletal remains can additionally be evidence of social organization (Parker Pearson, 1999; Rothschild, 2008) and temporal changes within cultures.

The ability of the skeleton to record certain aspects of an individual's lifestyle is often termed embodiment. When bioarchaeologists investigate the effects of biomechanical stresses on the human skeletal remains of past peoples, they literally study the embodiment of the labor process. They study labor as it is imprinted on the human skeleton through habitual action, rather than through the artifacts and features produced secondarily. As a record of individuals' labor demands, the human skeleton can also embody the history of social relationships because it is affected by those relations (Rothschild, 2008; Sofaer, 2006). Since the daily activities of individuals are governed by culture, and more specifically their subsistence strategies and social status, the embodiment of activity by the skeleton is here used to make interpretations about social structure as it is defined by the distribution of labor evident at Tipu.

The embodiment of activity by the human skeleton is made possible by the plasticity of both its soft and bony tissue (Virchow, 1872), and the plasticity of the skeleton is the foundation of this methods applied in dissertation. Plasticity refers to the process of functional adaptation to both natural and cultural environments, not evolutionary processes (Sofaer, 2006; Virchow, 1872), and in this case contributes to skeletal remodeling. Skeletal remodeling that occurs in order to maintain the integrity of bone given the forces of weight bearing and muscle action that act on it (Cowin, 2001; Goodship and Cunningham, 2001; Lanyon et al., 1982; Lanyon, 1987; Rubin et al., 1990; Wolff, 1892) is referred to as bone functional adaptation, and it makes possible the interpretation of past lifeways from the skeleton (Lanyon, 1982; Lanyon and Skerry,

2001; Pearson and Lieberman, 2004; Ruff et al., 2006). An extensive body of work demonstrates that activity induced stresses on the skeleton leads to deposition of bone to accommodate biomechanical forces, and inactivity leads to bone resorption (Demes, 2007; Goodship et al., 1979; Gosman et al., 2011; Hirschberg, 2005; Lanyon, 1982; Lanyon and Rubin, 1984; Lee et al., 2002; Martin et al., 1998; McKenzie and Silva, 2011; Robling et al., 2006.; Woo et al.,1981). The variety of ways in which humans have decided to deal with everyday problems of subsistence have led to the cultural differences among human groups, and these decisions also impact the skeleton because they govern the habitual actions of individuals.

In this study, the embodiment of lifestyle is observed from the cross-sectional morphology (CSG) of long bones and the development of bone at entheses (muscle insertion sites). The principles of bone functional adaptation and plasticity are particularly well demonstrated by bioarchaeological and *in vivo* studies of long bone CSG. The biomechanical forces applied to the shafts of upper and lower limb long bones through habitual muscle activity and weight bearing have been repeatedly shown to influence a bone's cross-sectional shape and robusticity (Haapasalo et al., 2000; Jones et al., 1977; Kannus et al., 1995; Kontulainen et al., 2003; Larsen et al., 1995; Larsen, 2002; Ledger et al., 2000; Maggiano et al., 2008; Ogilvie and Hilton, 2011; Shaw and Stock, 2009). Anthropologists have used CSG to investigate a variety of research questions related to human variation and the biomechanics of the human skeleton. Research topics include: evolutionary trends in long bone morphology from early *Homo* to modern humans and their corresponding behavioral changes, the effects of subsistence strategies, mobility patterns and terrain on long bone morphology, and the effects of activity level and age on the skeleton (Larsen, 2002; Ruff, 2008).

The development of bone at entheses on the skeleton is also assumed to represent muscle use (i.e. greater enthesis development coincides with more frequent use of the corresponding muscle). However, the evaluation of stresses applied to the skeleton through muscle use is evaluated by the morphology of bone at the individual points where muscles insert on long bones (Hawkey and Merbs, 1995; Mariotti et al., 2004; 2007; Villotte et al., 2010). In this study, the *development* of entheses refers to their

surface area, which is influenced by entheses area and rugosity (roughness). Although the actual magnitude and repetitiveness of muscle action required to induce hypertrophy of bone is not well understood (Cardoso and Henderson, 2010; Pearson and Buikstra, 2006; Zumwalt, 2006), there is a link between increased stress on muscles/tendons and bone morphological changes (Gosman et al., 2011; Niinimaki, 2009; Villotte, 2010). Support for the assumption that entheses development correlates with activity patterns comes primarily from studies of archaeologically recovered human skeletal remains that show entheses to be reflective of a past population's subsistence strategies and changes therein over time (Chapman, 1997; Eshed et al., 2004; Hawkey and Merbs, 1995; Molnar, 2006; Peterson, 1998; Robb, 1998; Spielmann et al., 2009; Steen and Lane, 1998; Weiss, 2003b; 2007). Recent studies that consider skeletal samples of individuals with known occupations also conclude that entheses morphology is related to individuals' daily workloads (Niinimaki, 2009; Villotte et al., 2010).

Dissertation Outline

Recall that this dissertation investigates the broad topic of social changes that accompanied Spanish missionization at Tipu. It more specifically investigates the nature of the community's social structure from the perspective of skeletal evidence of the distribution of labor at the site. Bone functional adaptations constitute the skeletal evidence of labor and include entheses development and the cross-sectional morphology of long bones. Chapter 2 is an evaluation of the utility of the new 3D method employed to quantify the entheses development. Chapters 3 and 4 investigate patterns of variation in bone functional adaptations among the Maya at Tipu. Chapter 3 investigates variation in the development of upper limb entheses among Tipu burial groups and pre-contact elites and non-elites to assess variation in upper limb muscle use. Chapter 4 investigates variation in the cross-sectional geometry of humeri, femora, and tibiae among the same burial groups to assess variation in mobility patterns and upper limb robusticity. The final chapter is a summary of the conclusions made from both studies of bone functional adaptations.

Chapter 2.

3D Representation and Analysis of Enthesis Morphology

Introduction

Bioarchaeologists seeking to reconstruct the physical behaviors of past human groups assume that the morphology and degree of bone development at entheses, or muscle insertion sites, on the skeleton are indicators of habitual muscle use. Support for this assumption comes primarily from archaeologically recovered human skeletal remains where: 1) temporal change in a group's subsistence strategy or hunting technology coincide with change in patterns of entheses development, 2) the muscle actions required by a particular technology are observable in patterns of entheses development, and 3) differences in male and female entheses development support archaeologically inferred, and in some cases ethnohistoric descriptions, of sexual divisions of labor (Chapman, 1997; Eshed et al., 2004; Hawkey and Merbs, 1995; Molnar, 2006; Peterson, 1998; Robb, 1998; Spielmann et al., 2009; Steen and Lane, 1998; Weiss, 2003b; 2007). Recent studies that consider skeletal samples of individuals with known occupations also conclude that labor intensity is a good predictor of MSM morphology (Niinimäki, 2009) and that the presence of upper limb fibrocartilaginous enthesopathies is significantly more frequent in men engaged in heavy manual labor than men engaged in non-manual or light manual labor (Villotte et al., 2010).

However, the reliability of entheses for inferring habitual muscle use has been called into question (Cardoso and Henderson, 2010; Stirland, 1998; Wilczak and Kennedy, 1997; Zumwalt, 2006). Criticisms focus on the following: uncertainty in the nature of muscle use and duration of activity required to produce an increase in entheses frequency or rugosity (Cardoso and Henderson, 2010; Stirland, 1998; Zumwalt, 2006); assignment of a particular behavior/activity to archaeological skeletal remains without the presence of experimental controls; and high inter- and intra-observer error rates coupled with low statistical power in traditional qualitative scoring methods (Wilczak and Kennedy, 1997).

Additionally, attention has been drawn to the differential effects of fibrous and fibrocartilaginous muscle insertions on bone (Benjamin et al., 1986; Benjamin and Ralphp, 1998; Benjamin et al., 2002), the importance of distinguishing between the two, and eliminating pathological cases (Benjamin and McGonagle, 2001) when assessing and interpreting enthesis development (Villotte, 2006; Villotte et al., 2010). Fibrocartilaginous attachments occur close to long bone epiphyses and represent more direct tendon attachments with short moment arms (e.g. the biceps brachii insertion on the proximal radius) (Benjamin and Ralphp, 1998). Fibrous attachments generally occur on long bone diaphyses, cover larger surface areas, and represent indirect muscle insertion sites (e.g. the deltoid tuberosity of the humerus) (Benjamin and Ralphp, 1998). Fibrocartilaginous attachments are often called 'direct' because the line of force from muscle action is more perpendicular to the bone cortical surface, and fibrous attachments are referred to as 'indirect' because the line of force from muscle action in relation to the cortical surface is much less than 90 degrees (Benjamin and Ralphp, 1998). It is important to consider enthesis type when conducting and interpreting analyses of enthesis morphology because each type is influenced differently by activity-induced stress depending on its location, the size of the attachment area and the type of tissue exerting force (Cardoso and Henderson, 2010).

For example, the force applied by the deltoid at the deltoid tuberosity is much more diffuse than the force applied by the biceps brachii at the radial tuberosity due to differences in the size of each insertion, the type of tissue that attaches to the periosteum, and the direction of force applied at each insertion by muscle action. The deltoid attaches to a large area of bone at the midshaft of the humerus and contraction of the muscle fibers, which are almost parallel to the diaphysis, places indirect stress on a large area of bone. In contrast, the biceps tendon places stress on a small area of bone on the radius and has a much more direct line of force when the bicep is contracted due to the more proximal location of the insertion site. The large attachment of splayed muscle fibers for the deltoid distributes force from muscle contraction over a larger area, whereas the biceps tendon has greater tensile strength (Benjamin and Ralphp, 1998) and focuses stress from muscle contraction in a very small area. The different forms of the deltoid

tuberosity and the radial tuberosity reflect these different types of forces and the different anatomies of the deltoid and biceps brachii (Benjamin and Ralphs, 1998).

This paper addresses the criticism that qualitative scoring methods (Hawkey and Merbs, 1995; Mariotti et al., 2004; Mariotti et al., 2007) for describing and analyzing enthesis development have high inter- and intra-observer error rates and low statistical power (Wilczak and Kennedy, 1997). Attempts have been made to improve the accuracy of enthesis scoring procedures with more incremental robusticity categories and example pictures for visual comparison, but inter- and intra-observer error rates remain as high as 28% (Mariotti et al., 2007). Qualitative analyses that employ a presence/absence technique have much better error rates (Cardoso and Henderson, 2010; Villotte, 2006; Villotte et al., 2010). Villotte and colleagues (2010) report inter- and intra-observer error rates less than 10%. However, a presence/absence enthesis study of known occupation groups that also includes fibrous entheses produced results that conflicted with those of Niinimäki (2009) and do not support correlation between enthesis development and activity (Cardoso and Henderson, 2010).

Another suggested solution has been to quantify, rather than categorize, entheses (Henderson and Gallant, 2007) using two-dimensional (2D) areas (Wilczak, 1998) and three-dimensional (3D) surface areas (Nolte and Wilczak, 2010; Zumwalt, 2005). 2D areas account for enthesis size, overlooking surface topography and therefore rugosity. 3D scanning technology provides a way to quantify both enthesis size and rugosity by measuring surface topography within the true boundaries of the insertion site (Nolte and Wilczak, 2010; Zumwalt, 2005). Creating 3D representations of entheses presents the study of entheses with new ways to assess their complexity (e.g. Evans et al., 2006) and shape (e.g. Mitteroecker and Gunz, 2009) using different software programs. 3D scanning may also offer a better way to assess the morphology of fibrous entheses. Since Cardoso and Henderson's (2010) presence/absence study did not demonstrate a strong relationship between enthesis development and activity, and Villotte and colleagues' (2010) study of only fibrocartilaginous entheses did, perhaps presence/absence methods are not as straight-forward for fibrous entheses. This may be due to the less direct and more diffuse nature of force that is applied to an enthesis like the deltoid tuberosity by

muscle action. Since the force applied to a fibrous enthesis by tendons is not as direct and focused as that of a fibrocartilaginous enthesis, bony changes that may be inspired by muscle action might be more subtle and therefore not as effectively represented by a present/absent method. Although it cannot be tested here on a known occupation sample, fibrous entheses especially may be more accurately represented by 3D surface areas.

This research investigates the comparability of three enthesis measurement methods: ordinal scoring, 2D measures and 3D measures. Fibrous and fibrocartilaginous entheses from a sample (n=24) of middle-adult males excavated from the Pottery Mound Site (LA 416) in central New Mexico were assessed with both ordinal and quantitative procedures. The new ordinal method developed by Mariotti and colleagues (2007) was excluded due to the method's high intra-observer error rate, and the author's inexperience with the method. Villotte's (2006) presence/absence method was also excluded because a goal of this study is to determine whether ordinal data that involve incremental scores for enthesis morphology produce similar results to those of the new 3D method, which essentially quantifies the intricacies of an enthesis.

Tests for enthesis asymmetry and degrees of correlation among the three methods were used to evaluate the results of each method in relation to one another, and the reliability of the 3D method was assessed with intra-observer error rates and Cronbach's alpha tests (Cronbach, 1951). Summary statistics were used to assess the amount of variation present in each data set and whether each data set violated assumptions of normality. Tests for enthesis asymmetry showed whether methods agreed upon which entheses were significantly more developed between right and left elements, and the degree of correlation among data sets was used to assess agreement in each method's representations of enthesis development. The main hypothesis tested is that 3D, 2D and ordinal methods will not agree in the data they provide about enthesis development. This is based on the very different ways in which each method "describes" the entheses. Ordinal scores representing grades of development are very different from quantitative values for both 2D areas and 3D surface areas that are on a continuous scale. The 2D area of an enthesis is only a measure of size, while a 3D surface area is a measure of both size and surface topography. It is also hypothesized that the 3D method is a replicable

method for measuring enthesis development. This hypothesis was tested by calculating intra-observer error rates and performing Cronbach's alpha tests. The goal is to identify advantages and disadvantages to each method, and to identify which, if any, methods agree in their results.

Materials and Methods

For this comparison of methods, four fibrous and three fibrocartilaginous entheses on the upper limb long bones (humeri, radii, and ulnae) of 24 adult males from the Pottery Mound Site (LA 416) in central New Mexico were recorded using the scoring method designed by Hawkey and Merbs (1995) with additional increments of 0.5 (Chapman, 1997), 2D areas (Wilczak, 1998), and 3D surface areas. The entheses analyzed were chosen because they are representative of a variety of motions about the shoulder and elbow. Actions represented include: shoulder abduction, adduction and medial rotation, elbow flexion, and forearm supination and pronation. No individuals in the sample have skeletal evidence for seronegative spondyloarthropathies or diffuse idiopathic skeletal hyperostosis (DISH), which are pathological conditions known to influence enthesis development (Benjamin and McGonagle, 2001; Resnick and Niwayama, 1983; Slobodin et al., 2007). There is also no evidence of trauma that would have affected activity patterns. The sample represents all of the most complete skeletons of middle-aged adult males excavated from the site. Residents of Pottery Mound were Puebloan agriculturalists whose activities would have centered on planting, tending and harvesting crops, as well as hunting/gathering, and building and maintaining pueblo structures and irrigation systems (Hibben, 1975; Mercer, 1985; Vivian, 2007). Pottery Mound was occupied from about 1300 - 1475 AD, and consists of 500 or more rooms, situated around four large plazas and 17 kivas (Hibben, 1975; Vivian, 2007). Complex irrigation systems were constructed to utilize water from the alluvial plain along the Rio Puerco for growing corn (Mercer, 1985). Hunting and trapping on the surrounding plains provided the community's primary protein sources (Clark, 2007).

The sex and age of individuals was determined using techniques described by Bass (1995) and Buikstra and Ubelaker (1994). Pelvic morphology was the primary indicator of sex, since elements of the pelvis were present for each individual. Because entheses development correlates with age (Cardoso and Henderson, 2010; Weiss, 2003a) only middle-aged adult males (35-50 years at death) were selected for analysis. All individuals in the collection fitting these criteria were included in the sample for this study.

The effects of body size on entheses development were assessed with summary statistics of body mass estimates and Spearman's rho correlations between body mass estimates and each ordinal, 2D and 3D data set (Table 2.1). Body mass for each male was estimated using femoral head diameter (Ruff et al., 1991). There does not appear to be drastic variation in body size within this sample, and there does not appear to be a large effect of body size on entheses size or morphology. Mean body mass estimates for these 24 males is 63.30 kg, with a standard deviation of 5.35 kg and a standard error mean of 1.09 kg. Kurtosis and skewness values lie between two and negative two, therefore body mass estimates conform to a normal distribution and there are no extreme outliers (Johnson and Bhattacharyya, 2006). Tests for correlation between body mass, ordinal scores, 2D areas and 3D surface areas did not consistently yield high correlation coefficients, but there does seem to be some effect of body size on entheses development. The maximum correlation coefficients were 0.84 for the right bicep in the 3D data set and 0.66 and 0.69 for the right and left brachialis entheses, respectively, in the 2D data set. All other coefficients did not exceed 0.58 and were not significant. The lack of consistent correlation between upper limb entheses surface areas and body size is not surprising because lower limb entheses have been shown to have higher correlations with body size (Weiss, 2004). Because body size did not correlate consistently with entheses development, absolute 3D surface areas and 2D areas were used in all subsequent analyses and were not standardized by body mass.

Table 2.1: Spearman's Rho correlations for evaluating effects of body size

Body mass estimates x 3D surface areas													
pectoralis		teres major		deltoid		brachialis		supinator		bicep		pronator	
R	L	R	L	R	L	R	L	R	L	R	L	R	L
0.56	0.44	0.15	0.40	-0.37	-0.04	0.27	0.54	0.30	0.53	0.84*	0.44	-0.10	--
Body mass estimates x 2D areas													
0.58	0.34	0.38	0.21	0.15	0.24	0.66	0.69*	0.31	0.56	0.36	0.53	-0.04	--
Body mass estimates x Ordinal scores													
0.04	0.18	0.09	0.19	0.18	0.01	-0.14	-0.50	0.07	0.17	--	0.45	0.48	0.53

*indicates significant correlations

Table 2.2 lists the entheses that were evaluated on right and left elements of the upper limb. Entheses were first scored using the Hawkey and Merbs (1995) qualitative method. Table 2.3 summarizes the description of each category used to score entheses/musculo-skeletal stress marker (MSM) robusticity (Hawkey and Merbs, 1995). No stress lesions were observed among this sample of males so individuals only received scores from 0 to 3 (Figure 2.1). Increments of 0.5 were also used when an enthesis's morphology was intermediate between two main categories (Chapman, 1997). If an enthesis had more surface topography than just a rounding of cortex described by category 1, but its borders remain ill-defined, it was given a score of 1.5. If an attachment had more prominent elevation than described by category 2, but remained rounded (without sharp crests), it was given a score of 2.5 (Chapman, 1997).

Table 2.2: Entheses analyzed

Enthesis	Joint and Action	Location	Type
Pectoralis major	Medial shoulder rotation	Humerus	Fibrous
Teres major	Medial rotation and shoulder adduction		Fibrous
Deltoid	Shoulder abduction		Fibrous
Brachialis	Elbow flexion	Ulna	Fibrocartilaginous
Supinator	Forearm supination		Fibrocartilaginous
Biceps brachii	Forearm supination and elbow flexion	Radius	Fibrocartilaginous
Pronator teres	Forearm pronation		Fibrous

Table 2.3: Hawkey and Merbs (1995) categories for MSM robusticity

Score	Description	Development Rating
0	cortex at insertion site is completely smooth and continuous with normal cortex	Absent
1	only slight rounding of cortex apparent to the touch and otherwise difficult/impossible to see	Faint
1.5	attachment area is more rugose in texture, but its borders are not defined	
2	more uneven cortical surface with an apparent mound-shaped elevation but no sharp ridges; may also involve apparent rough texture with well-defined borders	Moderate
2.5	attachment has more prominent elevations, but they remain rounded	
3	very distinct, sharp crests that may create deep indentations between the insertion site and surrounding cortex	Strong



Figure 2.1: Examples of Hawkey and Merbs (1995) Scores for the Pectoralis Major

A Nextengine® 3D laser scanner was used to determine both the 3D surface areas (cm²) of entheses and their 2D areas (cm²). Margins of each muscle insertion site were outlined with chalk for better digital visibility prior to scanning. Enthesis margins were determined visually, under strong light, with no magnification. Chalk was placed on the normal, smooth cortex just outside the irregular, rugose and/or upraised cortex of

insertion sites so that all measurements taken from the innermost border of the chalk outline captured all surface topography present. Once all entheses on the right and left radius, ulna and humerus of each individual were chalked, each long bone was scanned. The turntable was placed 6" from the scanner. Eight divisions were used for all scans, which means for each 360° turn of a long bone the scanner captured eight 3D images of the bone's surface. These eight scans were then reconstructed with Nextengine's® Scan Studio HD® software (2006-2010). Figure 2.2 is a demonstration of Scan Studio's acquisition window with a view of a humerus with entheses outlined in chalk.

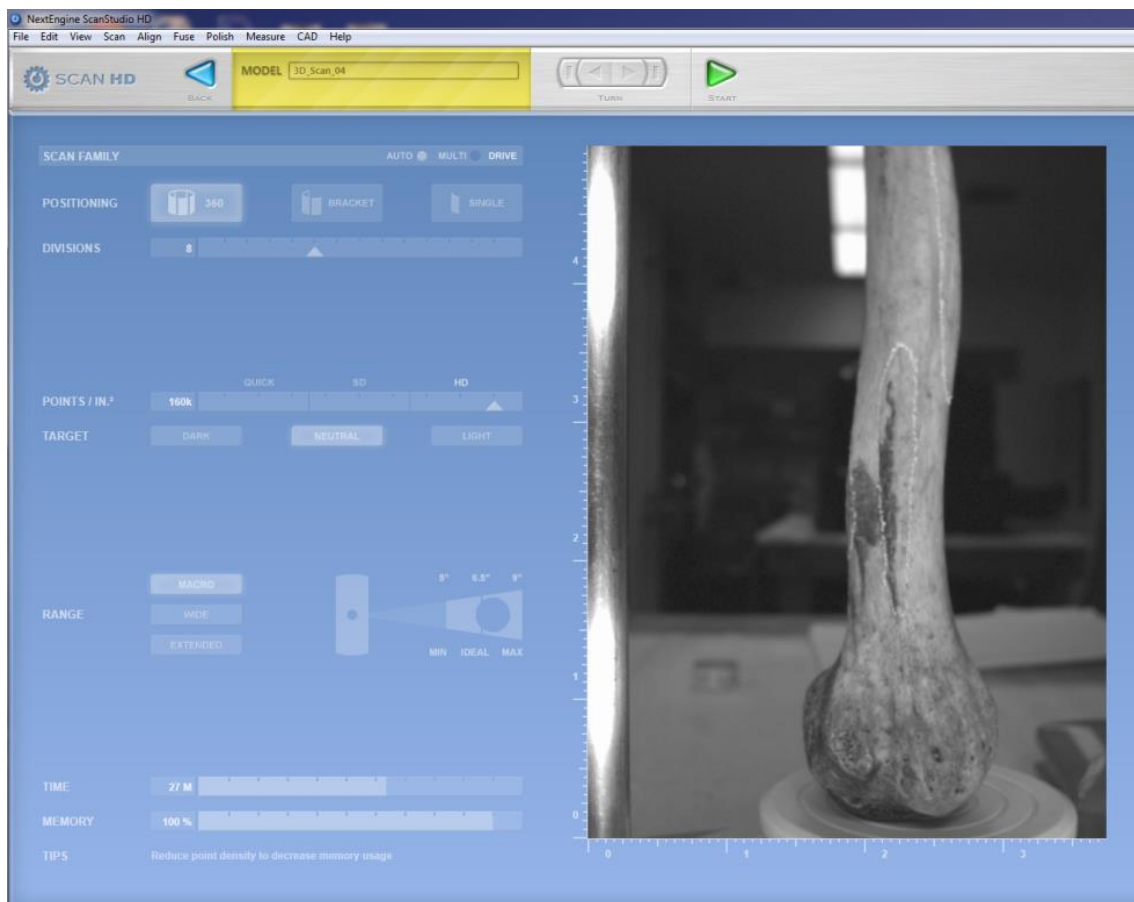


Figure 2.2: Example of ScanStudio's Acquisition Window and Chalked Entheses

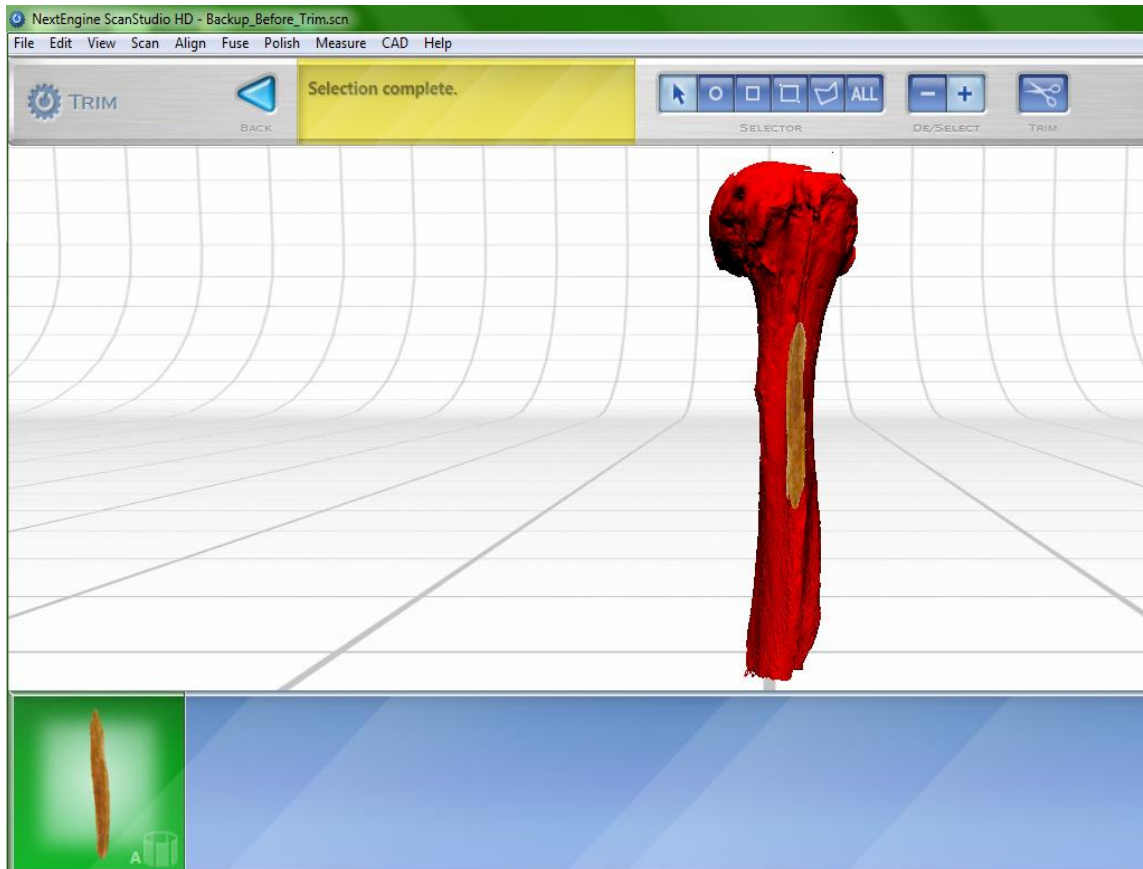


Figure 2.3: Example of Trimming Image for Measurement of Pectoralis Enthesis Surface Area

Using the same software, each long bone image was cropped so that only images of entheses within chalked outlines remained (Figure 2.3), and their 3D surface areas (cm²) were measured. Table 2.4 contains the scanner's default specifications in macro mode.

Table 2.4: Nextengine 3D laser scanner specifications (macro mode)

Field Size	5.1" x 3.8" / 13cm x 9.7cm
Resolution	geometry point density: 200 DPI
Texture Density	400 DPI
Dimensional Accuracy	+/- 0.005" / +/-0.127mm
Acquisition Speed	50,000 processed points/second throughput (~2min per scan)

3D images were then imported into Rapidform Explorer® (2011) software to determine the 2D area (cm²) of each enthesis (Figure 2.4). Measurements were made following Wilczak's (1998) method. However, instead of orienting the bone so that the maximum height and width of each enthesis was visible and therefore traceable (Wilczak,

1998), the 3D *image* of each bone scanned was oriented properly and each enthesis was traced and measured digitally in Rapidform®. Each element's 3D model was oriented proximo-distally with the maximum height and width of the enthesis of interest visible. The software's *x*, *y*, and *z* planes of reference were used to orient the model so that the maximum height and width were parallel with the viewing plane. The free hand tool was then used to trace the outline of each enthesis and measure its 2D area (Figure 2.4).

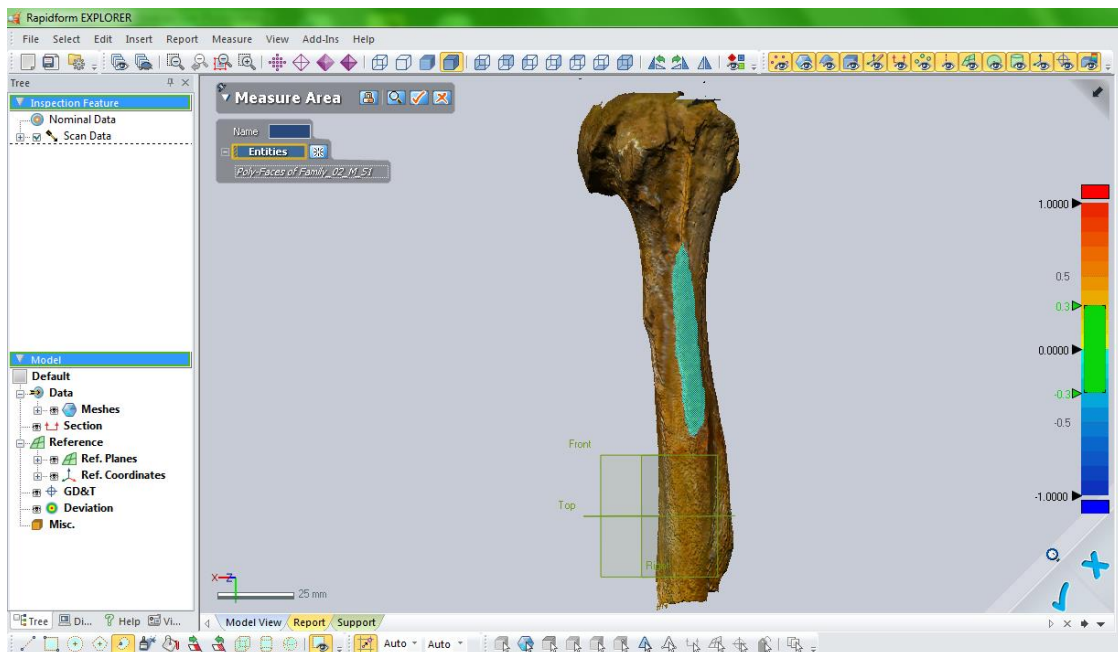


Figure 2.4: Example of Measuring the Pectoralis Enthsis for 2D area in Rapidform Explorer

The three data sets were compared using the following statistics. Summary statistics for each variable in each quantitative data set, including means, standard deviations, kurtosis, skewness, and Shapiro-Wilk tests (Shapiro and Wilk, 1965) were assessed for normality. Paired t-tests for enthesis asymmetry were performed within each quantitative data set and Kruskal-Wallis (Kruskal and Wallis, 1952) tests were used to test for asymmetry in the ordinal data set. In addition, values for right entheses were divided by values for left entheses to assess whether the right/left ratios of each data set had similar patterns, and Spearman's rho correlation coefficients (Corder and Foreman, 2009; Spearman, 1904) were used to assess correlation between right and left entheses.

Results of these tests were then compared to determine whether each method agrees on patterns of enthesis asymmetry.

Average percent measurement error rates and Cronbach's alpha values (Cronbach, 1951) were used to determine intra-observer error for the 3D method. A subset of individuals (n=12) that had adequate preservation of all right upper limb elements (humerus, radius and ulna) was chosen for re-measurement. All seven entheses were re-chalked and elements were re-scanned with the same method described above. All statistical tests listed above were performed in SAS 9.2 (2009).

Results

Summary statistics and Shapiro-Wilk test results for 2D and 3D quantitative data sets appear in Tables 2.5 and 2.6, respectively. Highlighted rows indicate variables with both high kurtosis and skewness values. Higher kurtosis indicates that more variance in a data set is due to infrequent extreme deviations and skewness is a measure of a distribution's asymmetry (negative values indicate left skewness, and positive values indicate right skewness). The standard acceptable value for both of these values is between two and negative two (Johnson and Bhattacharyya, 2006), so values outside that range are indicative of a non-normal distribution. Values for kurtosis and skewness, and Shapiro-Wilk tests all suggest that the variables in each quantitative data set are normally distributed, except for the right pronator in the 3D data set.

Tests for asymmetry in enthesis development demonstrate that 3D and ordinal data sets agree most often about which entheses are significantly different between right and left elements (Table 2.7). Ordinal data demonstrates all entheses analyzed as significantly asymmetrical except for the brachialis insertion. The same pattern is seen with 3D data. For all variables shown to be significantly asymmetrical, ordinal and 3D data sets also agree on whether the enthesis is most pronounced on the right or left element. Conversely, the 2D data does not agree with either 3D or ordinal data. Although the 2D data set agreed on which side the teres major, deltoid, and supinator entheses were more pronounced, it did not detect asymmetry in the pectoralis major or biceps brachii.

Table 2.5: Summary Statistics and Normality Tests for 2D Areas (cm²)

Variable	N	Mean	Std Deviation	Kurtosis	Skewness	Shapiro-Wilk p-values
R pectoralis	22	4.62	0.84	-0.50	-0.41	0.5125
L pectoralis	21	4.56	0.91	-0.09	0.45	0.8886
R teres major	21	2.12	0.52	-0.20	0.55	0.3414
L teres major	21	1.87	0.38	-0.17	0.04	0.7438
R deltoid	18	7.42	1.74	-1.11	0.15	0.4552
L deltoid	21	7.77	1.65	-1.04	-0.11	0.2565
R brachialis	17	2.74	0.63	-0.69	0.41	0.6796
L brachialis	17	2.80	0.68	0.14	-0.17	0.9997
R supinator	16	4.55	1.22	0.28	0.47	0.8928
L supinator	17	4.28	1.30	1.51	1.06	0.2737
R biceps brachii	11	3.58	0.89	1.97	0.06	0.4536
L biceps brachii	17	3.80	0.70	0.29	0.13	0.7581
R pronator	19	1.62	0.35	-0.60	-0.36	0.8436

Table 2.6: Summary Statistics and Normality Tests for 3D surface areas (cm²)

Variable	N	Mean	Std Deviation	Kurtosis	Skewness	Shapiro-Wilk p-values
R pectoralis	22	4.38	1.08	5.61	1.47	0.0045
L pectoralis	20	4.35	1.79	3.18	0.04	0.0707
R teres major	20	2.14	0.93	5.72	1.87	0.0048
L teres major	18	1.82	0.69	6.81	2.14	0.0018
R deltoid	19	6.59	1.92	1.91	-0.77	0.1186
L deltoid	21	7.85	2.13	1.26	0.69	0.4511
R brachialis	16	2.93	1.40	2.63	1.62	0.0055
L brachialis	20	2.62	1.03	1.12	0.99	0.1196
R supinator	16	4.58	1.74	0.92	0.90	0.3621
L supinator	20	4.14	1.69	2.65	0.90	0.1872
R biceps brachii	11	3.48	1.27	-0.11	0.52	0.8253
L biceps brachii	16	3.79	1.04	-0.01	0.44	0.6417
R pronator	17	1.43	0.63	11.30	3.08	0.0001

- highlighted row indicates kurtosis and skewness values > 2

Table 2.7: Tests for Enthesis Asymmetry

Enthesis	Hawkey and Merbs scores				2D areas (cm ²)		3D surface area (cm ²)	
	Chi-square	DF	p-value	side more pronounced	p-value	side more pronounced	p-value	side more pronounced
pectoralis	10.484	3	0.0149	Right	0.0544	---	.0384	Right
teres major	9.590	3	0.0224	Right	0.0268	Right	.0003	Right
deltoid	16.809	4	0.0021	Left	0.0009	Left	.0136	Left
brachialis	4.157	3	0.2449	---	0.0657	--	.3383	---
supinator	14.987	3	0.0018	Right	0.0002	Right	.0390	Right
biceps brachii	9.090	2	0.0106	Left	0.4287	---	.0006	Left
pronator	13.687	3	0.0034	Right	---	---	---	---

*Kruskal-Wallis tests were used for the ordinal data (Hawkey and Merbs 1995), and t-tests (Mann Whitney) were used for 2D and 3D data

*DF for all t-tests of 2D and 3D areas = 1

Spearman's rho correlation coefficients for right and left entheses data values also support the finding that ordinal and 3D data agree most on entheses symmetry. Correlations between each right and left variable in the ordinal and 3D data sets follow much the same pattern as probability values for statistical tests of asymmetry (Table 2.8). For each entheses that t-tests showed to be significantly asymmetrical, correlation coefficients are greater than 0.50, and the majority are greater than $\rho=0.67$. Variables selected as symmetrical have very low correlation coefficients for comparisons of right and left entheses. This is an indication that ordinal and 3D values that were not significantly different between right and left elements (for the brachialis) varied only slightly and inconsistently with one another. This observation could also be due to low variance in each variable compared and/or high measurement error. However, both sources of possible influence are not strong. The coefficients of variation for 3D surface areas of the right and left brachialis are 39%-48%, so there is not a low amount of variance for the variables, and relatively low intra-observer error results (described below) do not suggest that this observation is due to high measurement error. Enteses that were designated as significantly asymmetrical varied more, but right and left values varied in a consistent manner. In contrast, correlation coefficients for the 2D data are not consistent with t-test results.

Table 2.8: Spearman Correlation Coefficients for Asymmetry

Enthesis	Scores Right vs. Left	2D Right vs. Left	3D Right vs. left
pectoralis	0.72*	0.38	0.62*
teres major	0.57*	0.48*	0.70*
deltoid	0.82*	0.71*	0.58*
brachialis	0.43	0.68*	0.56
supinator	0.93*	0.86*	0.75*
biceps brachii	--	0.40	0.86*
pronator	0.89*	--	--

*indicates significant correlation

No clear cut patterns emerge from all possible comparisons of R/L ratios among data sets with Spearman's rho correlations (Table 2.9). No correlation coefficients exceeded 0.50 and none reach statistical significance. This is not surprising given the lack of agreement on entheses asymmetry between 3D and 2D data sets described above, and the fact that R/L ratios for ordinal scores are not on a continuous scale.

Table 2.9: Spearman Correlation Coefficients for R/L Ratios

Enthesis	3D vs. Scores	3D vs. 2D	2D vs. Scores
pectoralis	0.36	0.52	0.50
teres major	-0.17	-0.04	0.04
deltoid	0.39	-0.49	-0.50
brachialis	0.20	0.43	0.09
supinator	-0.10	0.01	-0.53
biceps brachii	--	-0.11	--
pronator	--	0.77	--

*indicates significant correlation

Comparisons of raw data values from the two quantitative data sets with Spearman's rho results show significant correlation between 3D and 2D data values for entheses development (Table 2.10). All coefficients were statistically significant, ranging from 0.56-0.91. This suggests that the two quantitative methods are comparable in representing entheses *size*. Inconsistency in the strength of correlations is likely due to the added information provided by surface topography in 3D data values. To summarize, lack of correlation between ordinal and 3D data is expected because the data vary on incremental and continuous scales, respectively. The two quantitative methods are correlated because both 2D and 3D measurements were measuring the same shape. Inconsistency in how well the 2D and 3D data correlate is due to the inclusion of rugosity in 3D measurements.

Table 2.10: Spearman Correlation Coefficients: comparisons of quantitative data sets

Enthesis	3D vs. 2D
R pectoralis	0.89*
L pectoralis	0.59*
R teres major	0.83*
L teres major	0.81*
R deltoid	0.60*
L deltoid	0.90*
R brachialis	0.57*
L brachialis	0.74*
R supinator	0.56*
L supinator	0.79*
R biceps brachii	0.67*
L biceps brachii	0.69*
R pronator	0.91*
L pronator	---

*indicates significant correlation

Intra-observer error tests for the 3D method resulted in average percent differences for all seven entheses that were between 10% and 15% (Table 2.11). All associated p-values from student's t-tests, except those for the deltoid ($p=0.0294$) and pronator ($p=0.026$), were between 0.0674 and 0.8214, so the majority of entheses had re-measurement values that were not significantly different from original measurements. Cronbach's alpha values for agreement between first and second observations fell between 0.68 and 0.73 (Table 2.12). These values span the lower end of the range for which agreement is considered satisfactory, which is 0.70 to 0.80 (Cronbach, 1951).

Table 2.11: Intra-observer Error Rates for 3D Method

Enthesis	avg. % difference
Pectoralis	10
Teres major	15
Deltoid	12
Brachialis	13
Supinator	14
Biceps brachii	14
Pronator	15

Table 2.12: Cronbach's (1951) Alpha Tests for Intra-observer Error

Variable	Standardized Variables	
	Correlation with Total	Alpha
Pectoralis	0.613923	0.682850
Teres	0.161255	0.734712
Deltoid	0.228025	0.727496
Brachialis	0.359148	0.712896
Supinator	0.491736	0.697542
Biceps brachii	0.343532	0.714665
Pronator	0.160323	0.734812

Discussion

Tests for intra-observer error tend to support the replicability of the 3D method by a single observer. However, inter-observer error is not reported here. Average percent measurement error rates between 10% and 15% (Table 2.11) are similar to those reported by other studies (Cardoso and Henderson, 2010; Villotte, 2006; Villotte et al., 2010). The majority of Cronbach's alpha values for first and second 3D measurements were within the minimum range for satisfactory agreement (0.70-0.80), however two were just under 0.70 (Table 2.12). Therefore, this method warrants further tests of intra- and especially inter-observer error.

Despite the expectation that 3D, 2D and ordinal methods for assessing entheses development would not agree in their results, an important result of this study suggests that 3D surface areas and ordinal scores are similar representations of entheses development. Both data sets agree about which entheses are significantly asymmetrical and on which side the insertion is more pronounced. Correlations between corresponding entheses of right and left elements also indicate a similar pattern of predictable variation for ordinal and 3D entheses values that were designated as significantly asymmetrical. In other words, both data sets produce a similar picture of habitual muscle use for males at Pottery Mound: men's' daily activities required left-biased use of the deltoid and biceps brachii, right-biased use of the pectoralis major, teres major and supinator, and bilateral use of the brachialis.

Considering the attributes of an entheses that ordinal scores and 3D surface areas represent, general agreement between the two methods is not necessarily surprising. When evaluating the morphology of an entheses and assigning a score, the observer is taking into account the rugosity, or roughness, of the insertion site, whether the area of rugosity is more or less distinct from normal cortex, and whether the insertion has pronounced bony crests (Hawkey and Merbs, 1995). Methods for visual inspection essentially take into account all the attributes of an entheses that a 3D representation of its surface area quantifies. Entheses with sharper crests and/or greater rugosity are represented by greater surface areas rather than a higher score. Entheses with less rugose texture are represented by smaller surface areas rather than a lower score.

The agreement between the 3D and ordinal data sets is also noteworthy because 3D surface areas take into account the size of an enthesis while ordinal scores do not. In this respect, 3D data would be expected to agree more with 2D representations of an enthesis' area. While 3D data did correlate with 2D data, the two data sets lacked agreement on enthesis asymmetry. The correlation of the two quantitative data sets is likely due to their shared accountability for enthesis size, however their lack of agreement on asymmetry was likely due to the added surface topography factor of 3D data.

In sum, intra-observer error tests for the 3D method show an improvement over error rates of 20% and greater for ordinal methods, but Cronbach's alpha values that border the minimum range for satisfactory agreement indicate the 3D method described here requires improvement. The hypothesis that the three data sets (ordinal, 2D and 3D) would not agree in their results is not supported because ordinal and 3D data tend to agree in results of tests for enthesis asymmetry, and 2D and 3D data values for enthesis development do correlate. Some subjectivity still exists in deciding where to chalk the margins of an enthesis to employ the 3D method, but measuring its 3D surface area is a promising avenue for quantifying entheses for bioarchaeological analyses.

Finally, as mentioned in the introduction, the author proposed that the 3D method for quantifying entheses may be a more accurate way to represent fibrous enthesis development, given the conflicting results from presence/absence versus ordinal methods about how well fibrous enthesis development correlates with activity (Cardoso and Henderson, 2010; Niinimaki, 2009; Villotte, 2006; Villotte et al., 2010). Although this could not be directly tested here with a known occupation sample, the results of this study suggest that the 3D method is a promising way to characterize both fibrous and fibrocartilaginous entheses because the two methods agreed on which entheses were asymmetrical regardless of their type.

Pros and Cons of Ordinal and 3D Methods

Ordinal and 3D quantification methods for representing enthesis morphology have advantages and disadvantages in terms of their utility in anthropological studies.

One drawback of the 3D surface area method is that a surface area value for enthesis morphology cannot be determined if part of the insertion is unobservable due to taphonomic damage. The left pronator teres was excluded from several statistical tests of quantitative data in this study because there were not enough data values for it, whereas it was still possible to assign a score based on the portion of the enthesis that was visible.

Ordinal methods are beneficial in that, once the method is learned, they are an easy and fast way to characterize enthesis development. A drawback of the 3D method is that it is less expedient. 3D scans slow down the rate of data collection and require additional image processing to measure desired attributes. 3D scanning technology, while now fairly inexpensive, is not "free" as ordinal scoring methods are, and may not be readily available to independent researchers outside of a lab setting. However, 3D surface areas are more precise representations of enthesis morphology because in addition to visible and tangible observation of an insertion site, they also account for its size. The only subjectivity introduced in the 3D method is in deciding where to chalk the margins of less pronounced entheses. Ordinal methods are more subjective and "coarse-grained" representations of enthesis development. The criteria that are used to determine a score of 0, 1, 2, or 3 create a detailed description of enthesis morphology, but enthesis size is ignored and more subtle variations in rugosity (i.e. features that can make assigning a score of a 1 versus a 2 difficult) are glossed over.

The 3D method for quantifying enthesis development is also advantageous because it opens new avenues for the assessment of enthesis morphology and shape using techniques such as geographic information systems (GIS) and geometric morphometrics (e.g Evans et al., 2006; Mitteroecker and Gunz, 2009). Evans and colleagues (2006) used GIS software to analyze 3D images of rodent teeth for shape independent of size and for complexity, which is a measure of the variation tooth cusps had in slope orientation and topographic elevation. 3D images of entheses could be subjected to the same measures of shape and complexity. These new approaches could be used to determine the effects of body size on enthesis development and to investigate complexity as a new measure of enthesis development. Since the nature and direction of force placed on the periosteum at a muscle insertion site varies between fibrous and fibrocartilaginous insertions, and it

varies among muscles based on the orientation of their fibers to the bone surface, perhaps entheses are better quantified with a measure of topography. In other words, in addition to the surface area of an attachment, the direction of forces applied to the bone surface by muscle action can also be accounted for with complexity.

Another benefit of using 3D scanning technology is that the 3D images produced can be used to create databases that can then be shared with other researchers. While spreadsheets of ordinal data can be easily shared, 3D scans of skeletal elements could be measured for other purposes by future researchers. This saves researchers costs of travel and there is no risk of damage to priceless skeletal collections. In addition, information about skeletal collections can be permanently preserved. Having 3D models of a site's human skeletal sample allows for retention of information even if the sample is repatriated. Future innovations in osteometrics can be used to revisit and learn more about a site and new research questions can be investigated without using the actual skeletons.

Conclusion

The most interesting result of this study is that two seemingly disparate methods for representing entheses morphology, ordinal scale and 3D data, paint a similar picture of patterns of entheses development for males at Pottery Mound. Given the findings reported here, larger sample studies similar to this one are needed. Because results of ordinal data sets seem to agree with those of the 3D quantitative data set, studies that employ one may be able to reasonably reference studies that employ the other to inform conclusions. While 3D scanning is a more costly and time-consuming way of assessing entheses development, it seems likely that the data produced will lead to more fine-grained results, especially when examining larger samples. A data set with values for entheses development that are continuous and normally distributed can be more thoroughly analyzed with higher statistical power. More studies that employ a similar method for measuring the 3D surface areas of entheses, and that also consider both inter- and intra-observer error, are needed. It would also be beneficial to substitute other

scoring methods for the one used here in a test of methods similar to this one (e.g. Mariotti et al., 2007).

Chapter 3.

Colonial Period Social Structure and Activity Patterns at Tipu from the Perspective of Upper Limb Enteses

Introduction

Spanish colonization in the Americas took a variety of forms and led to a variety of cultural outcomes for indigenous populations (Farriss, 1984; Gasco, 2005; Graham, 2011; Larsen et al., 2001). Even within the Maya Lowlands, a region encompassing what is now Yucatan, Campeche, Quintana Roo, Belize and part of Guatemala, the signatures of Spanish colonization were diverse. Many coastal villages in northern Yucatan were heavily occupied due to the economic exploits of Spaniards, and changes to indigenous lifeways were drastic. In contrast, the *visita* missions of central Belize were only visited occasionally by Spanish friars who wanted to ensure indigenous adherence to Christianity. Churches were constructed within communities of this region, but traditional lifeways continued (Graham, 2011; Jones, 1989; 1998).

This study uses the Colonial Period (AD 1544-1707) burial sample from Tipu as a case study for exploring the effects of missionization on the social structure of a Maya community at the periphery of Spanish colonization efforts. To date there is no archaeological or human skeletal evidence for social stratification within the Tipu burial sample, besides burial placement inside or outside the church walls (Cohen et al., 1994b; Danforth et al., 1997; Jacobi, 2000; Miller and Farriss, 1979; Muller-Wille, 1993; Wrobel, 2003). Here social structure is examined from the perspective of skeletal signatures of activity patterns, under the assumption that individuals of different social status engaged in different habitual behaviors.

Activity patterns among the Tipu burial sample are examined using the size and morphology of enteses on the humerus, radius and ulna as indicators of upper limb muscle use. A basis of comparison for evaluating the variation in upper limb enteses is provided by the same entesis data collected from samples of pre-contact Maya elites and non-elites. The ultimate goal is to determine whether activity patterns involving upper

limb musculature co-vary with burial placement at Tipu, and therefore by status within the Christianized community. Does the Tipu burial sample represent a community where the pre-contact hierarchy simply transferred to the newly established Christian community, or does it represent a community where the adoption of Christianity created a new social sphere where commoners had the opportunity to take on leadership roles?

This paper summarizes the historical and archaeological background of Tipu that inspired the research questions and hypotheses listed below. It also summarizes the applications and caveats of studies that use entheses to investigate past activity patterns. A new method for quantifying the size and morphology of entheses with three-dimensional (3D) surface area is detailed along with the results these data produced.

Research Questions and Hypotheses

This study addresses the following research questions:

- 1) Were pre-contact elite and non-elite Maya markedly different in upper limb enthesis development?
- 2) Are there significant differences among burial groups at Tipu in upper limb musculature?
- 3) How does the Tipu burial sample compare to pre-contact elites and non-elites in the size and morphology of upper limb entheses?

Answering the first research question establishes whether the samples of pre-contact Maya from disparate social tiers actually differed in upper limb muscle use. It also establishes a basis on which to evaluate variation among burial groups at Tipu. The second and third questions determine whether there is evidence from upper limb muscle use that there were distinct social tiers at Tipu. Question two establishes whether there is variation in upper limb musculature at Tipu that would suggest activity patterns varied by social status. For instance, it is expected that people of higher status would have engaged in less manual labor and therefore individuals buried inside the church structure should have different patterns of enthesis development than people of lower status interred

outside the church walls. Question three determines whether the activity patterns of Tipuans were more similar to pre-contact elites or non-elites and whether this also varied between burial locations. It will allow inferences to be made about whether a pre-contact social structure remained intact during the Colonial Period, or whether missionization created a new social sphere where commoners could become community leaders.

It should be noted that this is a simplified, working model and that a variety of factors, discussed in more detail below, could have contributed to the distribution of burials at Tipu. It is also understood that a dichotomous view of the Maya as either elite or non-elite, high or low status, is not necessarily representative of their pre- or post-contact society (Chase, 1992). However, the nature of both pre-contact comparative samples and the Tipu burial sample, and the nature of skeletal indicators of activity, do not allow examination of gradations in social status in this study. Pre-contact comparative samples were deliberately chosen to represent individuals at opposite ends of the Maya social pyramid, in order to determine whether their lifestyles were drastically different, as we often assume. These samples were also chosen with the idea that they would create the most contrast between pre- and post-contact social organization if there was in fact a reorganization of society within the Christianized Maya community at Tipu. Throughout this study pre-contact comparative samples are referred to as elite or non-elite, with the understanding that this is a simplified representation of Maya society. Elite refers to individuals who would have had more prestige, power and wealth than the rest of pre-contact Maya society (Chase and Chase, 1992; Sanders, 1992). Non-elite refers to individuals from rural, agricultural communities that were subsidiary to major Classic/Postclassic centers of political/economic power. Individuals at Tipu are referred to as high or low status based on their burial location inside or outside the church walls, respectively, again with the understanding that this is likely a simplified representation of their social status. Reference to Tipuans as either high or low status, rather than elite or non-elite, is meant to signify that it is not assumed that these pre-contact social tiers persisted in the Colonial Period.

To address each of the three questions listed above, the three associated hypotheses below are tested:

- 1) Since the lifestyles of Maya from different social strata varied (Adams, 1970; Chase and Chase, 1992), *pre-contact elite samples will have different patterns of upper limb entheses development than pre-contact non-elite samples.*
- 2) *Upper limb entheses development will be homogenous within the Tipu burial sample.*
This hypothesis is based on the lack of archaeological and human skeletal evidence for social differentiation (described below) among Tipu burial groups, and the finding that skeletal robusticity does not vary significantly by burial placement (Cohen et al., 1989; Wrobel, 2003).
- 3) *The Tipu burial sample will more closely resemble non-elites in upper limb musculature.* This hypothesis is based on archaeological evidence for continuity in subsistence strategies (farming and hunting/gathering) at Tipu, as well as historical evidence that some Maya non-elites had the opportunity for upward social mobility during the Colonial Period (Farriss, 1984).

Historical and Archaeological Background

Spanish colonization in Mesoamerica began with the arrival of Hernan Cortes in 1519. The Aztec Empire, which dominated the region from central Mexico and Guatemala to Honduras, was overthrown within a couple years of their arrival (Charlton and Fournier Garcia, 1993; Jones, 1989; Palka, 2009). However, it was not until 1527 that colonization and Catholic missionization of the Yucatan and Maya Lowlands began (Jones 1989). Longer still was the process of colonization and subjugation of indigenous groups in what is now Belize and the Petén region to the west (Jones, 1989; 1998), due to several cultural and environmental factors (Graham, 2011). The central and southern Lowlands (i.e. Belize) were not high priority for commercial exploitation because the region lacked resources that were of great value to the Spanish (i.e. gold and other precious metals) (Farriss, 1984; Graham, 2011; Jones, 1989; 1998). Maya political systems were also more fragmented, rather than highly centralized (as the Aztecs were), so they were more difficult to bring under control all at once (Cecil, 2009b; Farriss, 1984;

Jones, 1989; 1998). This problem was further confounded by the dispersed nature of Maya communities and their inaccessibility to Spaniards unaccustomed to the terrain and climate of inland locales of the frontier zone (Farriss, 1984; Graham, 2011; Jones, 1989; 1998). Efforts at *reduccion*, the forced consolidation of indigenous communities into one large, more easily controlled village, proved difficult, and such inland colonies were rarely maintained if Spaniards left (Jones, 1998). In sum, the initial conquest of Tipu and surrounding Maya communities was very different than it had been for populations of central Mexico (Farriss, 1984; Jones, 1989; 1998; Jones and Pendergast, 1991). In fact, Tipu was a refuge for people fleeing the more heavily controlled colonies of northern Yucatan where *repartimiento* (forced labor systems) negatively affected Maya lifeways (Farriss, 1984; Graham, 2011; Jones, 1998).

Tipu was a community in the Macal River Valley in west central Belize with archaeological evidence of continuous occupation from the Late Preclassic (~300 BC) through the Spanish Colonial Period (AD 1544-1708) (Graham, 1991; Jacobi, 2000). Franciscan missionaries were the primary colonizers of the region. Despite being greatly outnumbered by indigenous people, they established *visita* missions that endured (Graham, 2011). The mission at Tipu is documented both historically and archaeologically (Cohen et al., 1989; 1994a; 1994b; Graham, 1991; 2011; Graham et al., 1985; 1989; Jones, 1989; 1998; Scholes and Thompson, 1977). Despite inconsistent Spanish presence there, both lines of evidence suggest complete acceptance and persistence of Christianity from 1544 until the Maya there were forcibly removed in 1707 (Graham, 2011). Tribute was paid to the Spanish administration in goods that the Maya at Tipu had been producing centuries before contact (Graham, 2011). There are no documented demands for increased production (Danforth et al., 1997), and subsistence strategies were continuous throughout the Colonial Period (Emery, 1999). Therefore, it seems there were few changes in indigenous lifestyles that coincided with conversion to Christianity (Graham, 2011). Archaeological evidence indicates that use of Postclassic ritual structures continued into the Colonial Period (Graham et al., 1985). Spanish goods were found in association with Postclassic architectural features (Cohen et al., 1994a). In addition to continued use of Postclassic structures and ritual spaces, trade goods and

ceramics suggest Tipu remained part of the un-colonized Itzá Maya economic sphere (Cohen et al., 1994a; Jones, 1982).

Several lines of archaeological evidence indicate continuity in subsistence strategies at Tipu. There were no changes in slips, paints or general vessel appearance of locally produced pottery, no changes in lithic technology (Graham, 2011), and despite introduction of some metal tools by Spaniards, they never dominate assemblages (Graham, 1991). Faunal assemblages indicate a continuous, highly generalized use of a variety of animal species from all available ecosystems from the Postclassic through the Colonial Period (Emery, 1999), and continued trade for marine resources with coastal communities (Graham, 1991). Milpa farming was continually used to grow corn, squash, beans, chiles, sugar cane, and plantains. Production of cacao persisted because it remained a valuable commodity (Jones, 1982). In the Classic Period, cacao was the economic base of Tipu elites, and the Spanish accepted it as tribute in the Colonial Period (Jones, 1982; Graham et al., 1985). Documents written by Spanish friars indicate corn milpas were harvested two or three times per year, which suggests intensive cultivation during the Colonial Period (Jones, 1982). However, this intensity of cultivation is also documented among contemporary populations and was likely normal practice in pre-contact times to offset the danger of crop failure due to floods or unpredictable rainfall (Jones, 1982; Redfield and Villa Rojas, 1964).

Of interest here is whether continuity also existed in the social structure of the Christianized Maya community. European Catholic custom dictated that individuals of higher status be buried inside church structures, those of highest status be buried near the altar, and those of lower status be buried outside the church walls in cemeteries (Jacobi, 2000; Jones, 1989; Miller and Farriss, 1979; Muller-Wille, 1993). Interment of individuals in various places under the church floor, near the altar, and outside the church structure suggests there was some type of hierarchy in place at Tipu reflecting European custom. The historical record documents the presence of a ruling class at Tipu and names associated with elite lineages of the un-colonized Itzá Maya in the Petén region to the west (Jones, 1998; Scholes and Thompson, 1977). However, there is no archaeological or human skeletal evidence, besides burial placement, indicative of differential social status

among Maya individuals buried in and around the church structure (Cohen et al., 1994b; Danforth et al., 1997; Jacobi, 2000; Wrobel, 2003). If all segments of pre-contact Maya society were intact and all were indoctrinated into the Colonial Period Christian community, there should be at least some skeletal evidence of differential status within the church burial sample. Thus far none have been distinguished (Cohen et al., 1989; Cohen et al., 1994b; Jacobi, 2000; Wrobel, 2003). Skeletal signatures of nutritional deficiencies or illness (e.g. porotic hyperostosis) and stature do not vary significantly between individuals buried inside and outside the church walls (Cohen et al., 1989; Cohen et al., 1994b; Jacobi, 2000). Long bone robusticity is also relatively homogenous among the burial clusters at Tipu (Cohen et al., 1989; Wrobel, 2003). This suggests that individuals buried inside the church, and of presumably higher status, did not have significantly different lifestyles than other individuals buried within the context of the church. In other words, the leaders of the newly established Christian community were not the elites of the days before Spanish contact.

Entheses and Activity Patterns

To test the hypotheses listed above, this study employs analysis of entheses on upper limb long bones using a new method for measuring their three-dimensional (3D) surface areas (detailed in Methods section). The investigation of social status through variation in enthesis development, and by extension, variation in activity patterns, relies on two main assumptions. The first is that Maya elites and non-elites had different lifestyles based on primary involvement in administrative activities versus farming and hunting, respectively (Adams, 1970; Chase and Chase, 1992; Inomata and Triadan, 2000). The second assumption is that the development of entheses correlates with the degree of corresponding muscle use (i.e. greater enthesis development coincides with more frequent use of the corresponding muscle). In this case, the *development* of entheses refers to their surface area, which is influenced by enthesis area and rugosity. The more rugose an enthesis, the greater its surface area. The most common methods for analyzing enthesis development also focus on rugosity, but their data consist of ordinal scores that

are assigned based on descriptions of bone that incorporate degrees of rugosity, how well-defined enthesis margins are, and whether there are elevations (mounds or crests) or depressions (stress lesions) present (Hawkey and Merbs, 1995; Mariotti et al., 2004; 2007; Villotte, 2010).

An enthesis is defined as the junction between a tendon or ligament and bone (Benjamin and Ralphs, 1998). Bioarchaeologists seeking to reconstruct the physical behaviors of past human groups assume the morphology and degree of bone development at muscle insertion sites, or entheses, on the skeleton are indicators of habitual muscle use. It is well known that bone responds to muscular stress through morphological change (Chapman, 1997; Gosman et al., 2011; Hirschberg, 2005; McKenzie and Silva, 2011; Robling et al., 2006), and this is often termed bone functional adaptation (Lanyon, 1982; Lanyon and Skerry, 2001; Pearson and Lieberman, 2004; Ruff et al., 2006). This principle is particularly well demonstrated by bioarchaeological and *in vivo* studies of the cross-sectional morphology of long bones. The biomechanical forces applied to the shafts of upper and lower limb long bones through habitual muscle activity and weight bearing have been repeatedly shown to influence a bone's cross-sectional shape (Haapasalo et al., 2000; Jones et al., 1977; Kannus et al., 1995; Kontulainen et al., 2003; Larsen et al., 1995; Larsen, 2002; Ledger et al., 2000; Maggiano et al., 2008; Ogilvie and Hilton, 2011; Shaw and Stock, 2009).

Development of bone at entheses (also called musculoskeletal stress markers [MSM] and muscle insertion sites) on the skeleton is also assumed to represent muscle use. However, the evaluation of stresses applied to the skeleton through muscle use is evaluated by the morphology of bone at the individual points where muscles insert on long bones (Hawkey and Merbs, 1995; Mariotti et al., 2004; 2007; Villotte et al., 2010). The application of stress to bone at an enthesis by the muscle, tendon or ligament that attaches there causes increased vascularization of the periosteum, which leads to osteonal remodeling and the hypertrophy of bone (Hawkey and Merbs, 1995; Chapman, 1997; Gosman et al., 2011). This hypertrophy of bone leads to a variety of bone morphology at insertion sites including (but not limited to): long mounds of bone (e.g. the deltoid tuberosity), narrow, oval-shaped mounds of bone (e.g. the pectoralis major insertion), or

spherical tubercles (e.g. the radial tuberosity). Gradations of rugosity can be observed at each of these types of insertions that range from slightly roughened cortex, to pronounced mounds of rough cortex, to sharp bony crests. This variety of enthesis morphology observed at insertion sites is influenced by activity, but it is important to keep in mind that human musculo-skeletal anatomy determines the base morphology of entheses. The effects of sex (i.e. hormonal differences) and age must also be considered (Gosman et al., 2011; Weiss, 2003a; 2004).

Entheses are characterized as fibrocartilaginous or fibrous, depending on the type of tissue (muscle fibers, ligaments or tendons) at the attachment and its proximity to long bone epiphyses (Cardoso and Henderson, 2010). It is important to note that many entheses are not simply one or the other because there is a continuum between the two types and one enthesis can have both fibrocartilaginous and fibrous components (Benjamin et al., 2002; Milz et al., 2001). Fibrocartilaginous attachments occur close to long bone epiphyses and represent more direct tendon attachments with short moment arms (e.g. the biceps brachii insertion on the radial tuberosity) (Benjamin and Ralphs, 1998). Fibrous attachments generally occur on long bone diaphyses, cover larger surface areas, and represent indirect muscle insertion sites (e.g. the deltoid tuberosity of the humerus) (Benjamin and Ralphs, 1998). Fibrocartilaginous attachments are often called 'direct' because the line of force applied to bone from muscle action is more perpendicular to the bone cortical surface. Fibrous attachments are referred to as 'indirect' because the line of force from muscle action in relation to the cortical surface is much less than 90 degrees (Benjamin and Ralphs, 1998). It is important to consider enthesis type when conducting and interpreting analyses of enthesis morphology because each type is influenced differently by activity-induced stress depending on its location, the size of the attachment area and the type of tissue exerting force (Cardoso and Henderson, 2010).

For example, the force applied by the deltoid at the deltoid tuberosity is much more diffuse than the force applied by the biceps brachii at the radial tuberosity due to differences in the size of each insertion, the type of tissue that attaches to the periosteum, and the direction of force applied at each insertion by muscle action. The deltoid attaches

to a large area of bone at the midshaft of the humerus and contraction of the muscle fibers, which are almost parallel to the diaphysis, places indirect stress on a large area of bone. In contrast, the biceps tendon places stress on a small area of bone on the radius and has a much more direct line of force when the bicep is contracted due to the more proximal location of the insertion site. The large attachment of splayed muscle fibers for the deltoid distributes force from muscle contraction over a larger area, whereas the biceps tendon has greater tensile strength (Benjamin and Ralphs, 1998) and focuses stress from muscle contraction in a very small area. The different morphologies of the deltoid tuberosity and the radial tuberosity reflect these different types of forces and the different anatomies of the deltoid and biceps brachii (Benjamin and Ralphs, 1998). For this reason, surface area data for each enthesis in this study were considered separately, and interpretations were made with the above concerns in mind.

Limitations of Entheses as Indicators of Activity

This study's underlying assumption that the development of bone at muscle insertion sites correlates with the degree of corresponding muscle use has been called into question (Cardoso and Henderson, 2010; Stirland, 1998; Wilczak and Kennedy, 1997; Zumwalt, 2006), mainly due to conflicting results about the correlation of activity with enthesis development (Cardoso and Henderson, 2010; Niinimäki, 2009; Villotte et al., 2010; Zumwalt, 2006). Criticisms of using entheses to make inferences about activity patterns focus on the following: 1) assignment of a particular behavior/activity to archaeological skeletal remains without the presence of experimental controls; 2) high inter- and intra-observer error rates coupled with low statistical power in traditional qualitative scoring methods (Wilczak and Kennedy, 1997); and 3) uncertainty in the nature of muscle use and duration of activity required to produce an increase in enthesis frequency or rugosity, as well as the strong effects of age on enthesis morphology (Cardoso and Henderson, 2010; Stirland, 1998; Zumwalt, 2006; Weiss, 2003a; 2004). Attention has also been drawn to the differential effects of fibrous and fibrocartilaginous muscle insertions on bone (Benjamin et al., 1986; Benjamin and Ralphs, 1998; Benjamin

et al., 2002), the importance of distinguishing between the two, and the importance of eliminating pathological cases when assessing and interpreting enthesis development (Benjamin and McGonagle, 2001; Villotte, 2006; Villotte et al., 2010).

In response to the first criticism, it is not a goal of this study to define the particular activities Maya individuals in each sample engaged in. To address the research questions of interest, *patterns* of similarities and dissimilarities (Robb, 1998) in upper limb musculature are explored among burial groups to determine whether there is evidence of social stratification within the Tipu burial sample. Particular activities that the Maya engaged in will be discussed, but only to provide an understanding of the types of behaviors that would have contributed to patterns of enthesis development. These patterns are seen as aggregates of all the habitual activities individuals engaged in throughout their lives.

As other researchers have suggested (Henderson and Gallant, 2007; Nolte and Wilczak, 2010; Zumwalt, 2005), this paper addresses the second criticism by quantifying (rather than categorizing) entheses using 3D surface areas. Measurement of two-dimensional (2D) enthesis area (Henderson and Gallant, 2007; Wilczak, 1998) has produced error rates lower than those of ordinal methods (Wilczak, 1998). However, 2D areas are only representations of enthesis size and they overlook surface topography (i.e. rugosity) (Henderson and Gallant, 2007; Wilczak, 1998). The use of 3D scanning technology provides a way to quantify both enthesis size and rugosity by measuring surface topography within the true boundaries of the insertion site (Nolte and Wilczak, 2010; Zumwalt, 2005). While the inter-observer error rate of the 3D method used in this study (detailed below) could not be assessed, low intra-observer error rates were calculated for the method in both a pilot study (Chapter 2) and with this study's data set. Error rates in the pilot study range from 10-15%, and from 4-8% for the data presented here.

While it is beyond the scope of this paper to address the third criticism, it is important to note that there is a link between increased stress on muscles/tendons and bone morphological changes (Gosman et al., 2011; Niinimaki, 2009; Villotte, 2010). Less straightforward is the actual magnitude and repetitiveness of muscle action required to

induce hypertrophy of bone (Cardoso and Henderson, 2010; Zumwalt, 2006). Support for the assumption that enthesis development correlates with activity patterns comes primarily from studies of archaeologically recovered human skeletal remains that show entheses to be reflective of a past population's subsistence strategies and changes therein over time (Chapman, 1997; Eshed et al., 2004; Hawkey and Merbs, 1995; Molnar, 2006; Peterson, 1998; Robb, 1998; Spielmann et al., 2009; Steen and Lane, 1998; Weiss, 2003b; Weiss, 2007). More recent studies that consider skeletal samples of individuals with known occupations also conclude that enthesis morphology is related to individuals' daily workloads (Niinimaki, 2009; Villotte et al., 2010).

In a study of a cadaver sample of 20th century Finns for whom age, sex and occupation were recorded, Niinimaki (2009) showed that labor intensity (heavy versus light manual labor), muscle size, side dominance, and age are good predictors of enthesis morphology. The presence of upper limb fibrocartilaginous enthesopathies is also significantly more frequent in men engaged in heavy manual labor than men engaged in non-manual or light manual labor (Villotte et al., 2010). Bioarchaeological studies have shown that temporal change in a group's subsistence strategy or hunting technology coincides with temporal change in patterns of enthesis development (Chapman, 1997; Eshed et al., 2004; Hawkey and Merbs, 1995; Spielmann et al., 2009). Differences in male and female enthesis development within past populations have also been used to investigate sexual divisions of labor, and in some cases were shown to reflect ethnographic/ethnohistoric descriptions of labor divisions (Chapman, 1997; Eshed et al., 2004; Hawkey and Merbs, 1995; Molnar, 2006; Peterson, 1998; Robb, 1998; Spielmann et al., 2009; Steen and Lane, 1998; Weiss, 2003b; Weiss, 2007).

A good example of temporal change in enthesis development, and one relevant to this study, is Spielmann and colleagues' (2009) study of Native American responses to Spanish colonization in the Salinas Pueblo region of central New Mexico. Of the nine pueblo sites from which they analyzed archaeological and zooarchaeological patterns of change that accompanied colonization, one site, Gran Quivira, also preserved human remains from both pre-contact and colonial period contexts. Entheses of the upper limb were recorded for males and females in the skeletal sample using Hawkey and Merbs'

(1995) ordinal method (Spielmann et al., 2009). From these data the authors found that the habitual activities of females before contact were distinct from those of males, and involved actions of the upper limb consistent with the motions required for grinding corn, scraping hides and agricultural tasks. During the colonial period, these types of behavior intensified in correspondence with faunal evidence for intensified hide processing. Both males and females also demonstrated an increase in enthesis development suggestive of carrying heavy burdens in front of the body and on the back during the colonial period. The authors concluded that these temporal changes in enthesis development reflect changes in activity patterns that resulted from the labor demands of Spaniards. Chapman (1997) reported similar conclusions in her study of entheses from pre- and post-contact skeletal samples at Pecos Pueblo. Both males and females demonstrated increases in enthesis development consistent with intensification of agriculture and bearing heavy burdens (Chapman, 1997).

Materials

To be included in this study, an individual's upper limb long bones had to have good cortical preservation and no taphonomic damage at enthesis sites. Since skeletal markers of biomechanical stress are assumed to be aggregates of lifetime activity, bone reaction to mechanical loading varies throughout ontogeny (Bass et al., 2002; Gosman et al., 2011; Kannus et al., 1995; Pearson and Lieberman, 2004), and enthesis development has been shown to correlate with age (Weiss, 2003a; 2004), juveniles (under age 18 at death) and adults over the age of 50 were excluded from this study. Individuals with evidence of severe trauma, such as abnormal ossification of muscle or ligamentous tissue (i.e. myositis ossificans - bony spicules projecting from muscle insertion sites), misaligned long bone fractures, or evidence of other pathologies that could have altered activity patterns were also excluded. No individuals in the samples analyzed have skeletal evidence for seronegative spondyloarthropathies or diffuse idiopathic skeletal hyperostosis (DISH), which are pathological conditions known to influence enthesis

development (Benjamin and McGonagle, 2001; Resnick and Niwayama, 1983; Slobodin et al., 2007).

The entheses analyzed are insertion sites for: the deltoid, teres major, and pectoralis major on the humerus, biceps brachii and pronator teres on the radius, and the supinator and brachialis on the ulna (Table 3.1). Based on the assumption that entheses morphology is a reflection of habitual muscle activity, these entheses were chosen because they are representative of a variety of muscle actions about the shoulder and elbow, and they were most often preserved among all skeletal samples. Specific muscle actions represented by the entheses listed here include: shoulder adduction, abduction and medial rotation, elbow flexion, and forearm supination and pronation.

Table 3.1: Entheses Measured for Surface Area

Element	Enthesis	Action and joint	Enthesis type
Humerus	Deltoid	Shoulder abduction, flexion and extension	fibrous
	Teres major	Medial rotation and extension at shoulder	fibrous
	Pectoralis major	Shoulder flexion, adduction, and medial rotation	fibrous
Radius	Biceps brachii	Elbow flexion and forearm supination	fibrocartilaginous
	Pronator teres	Forearm pronation	fibrous
Ulna	Supinator	Forearm supination	fibrocartilaginous
	Brachialis	Powerful elbow flexor	fibrocartilaginous

To aid in the interpretation of entheses development patterns observed within the Colonial Period Maya skeletal sample from Tipu, the same entheses listed above were also recorded for samples of pre-contact Maya elites and non-elites. All skeletal material analyzed comes from previously excavated and curated collections from central Belize. The elite comparative sample is comprised of individuals associated with monumental architecture at Cahal Pech and Baking Pot and elites from a cave context at Je'reftheel. The non-elite comparative sample includes individuals interred at Caves Branch Rockshelter and Actun Uayazba Kab (Table 3.2) (detailed site descriptions of all sites listed are included below). Tipu, Baking Pot, and Cahal Pech are located in the Upper

Belize Valley (Figure 3.1) of central Belize. Je'reftheel and Actun Uayazba Kab are located in the valley of Roaring Creek, which is a tributary of the Belize River, and Caves Branch Rockshelter is named for its location in the Caves Branch River Valley, which empties into the Sibun River.

All sites sampled are in a similar topographic region of central Belize at the northern edge of the Vaca Plateau and Mountain Pine Ridge to control for variation in skeletal responses to activity caused by interregional cultural and environmental differences. Cultural and environmental factors that would have influenced the use of upper limb musculature among Lowland Maya populations are essentially encompassed by regionally specific subsistence strategies and tribute requirements (Sharer, 1996). In other words, the daily activities of inland Maya communities engaged in milpa agriculture, arboriculture, and hunting and gathering in jungle and riverine ecosystems were different from those of coastal Maya communities that practiced wetland agriculture in swamps and focused on marine resources for subsistence. By extension, variation in the environmentally constrained resources available to Maya communities for subsistence also meant variation in resources available for exploitation and tribute demands made by elites (Sharer, 1996). The following is a brief summary of the environmental, cultural, and social factors that were the context for the daily lives of the Maya in central Belize.

Figure 3.1: Map of Study Area -- Upper Belize Valley

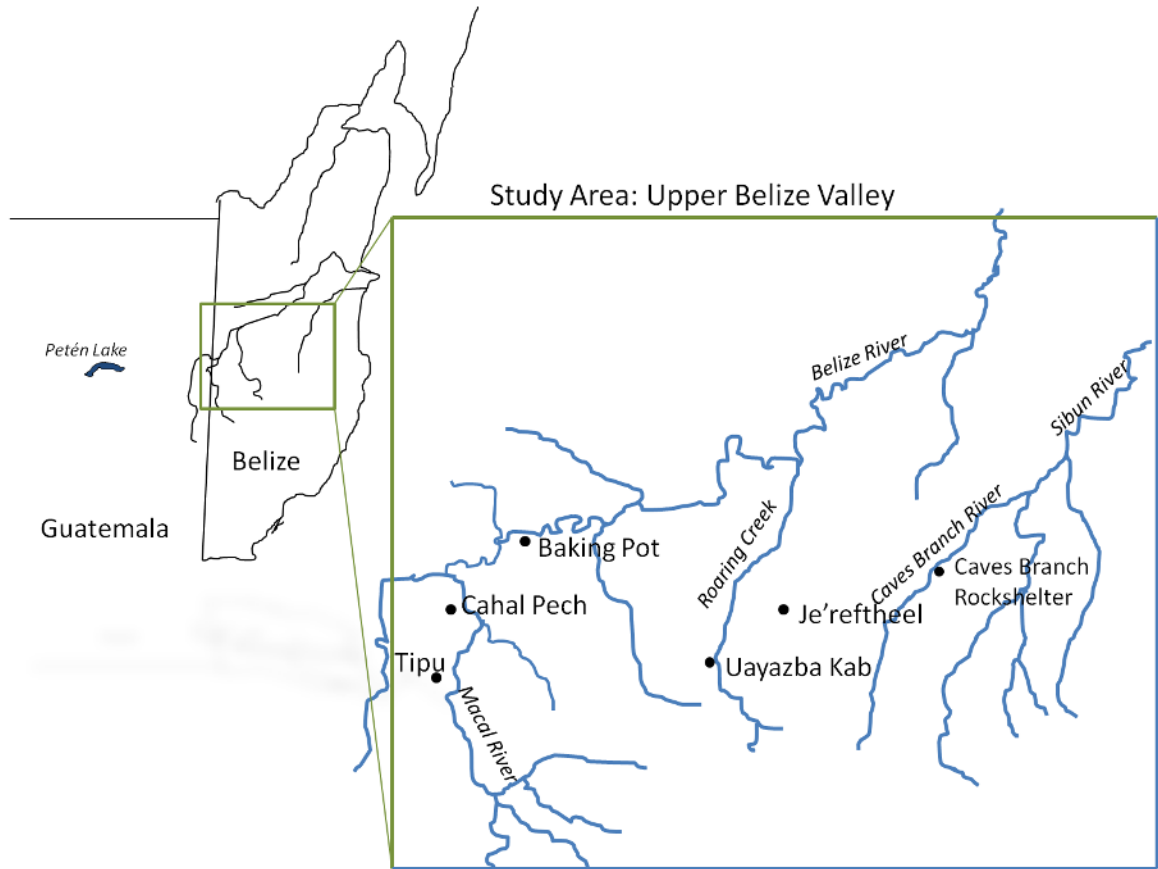


Table 3.2: Sample sizes

Site	total <i>n</i>	females	males
Tipu	57	24	33
Non-Elites:			
Caves Branch Rockshelter	37	18	19
Actun Uayazba Kab	2	2	--
Elites:			
Je'reftheel	22	10	12
Cahal Pech	3	--	3
Baking Pot	4	1	3

Most Maya settlements and major centers of the study region were located on or near rivers. Subsistence strategies in the Belize River Valley and surrounding regions from the Classic to Colonial Period involved milpa agriculture for growing maize, beans and squash, growing and harvesting cacao, hunting and gathering plant and animal species in the surrounding jungle, and exploiting river species such as fish and *jute* (snails) (Emery, 1999; Sharer, 1996). Travel along the Belize River and its tributaries via

dugout canoes was also frequent because the river was a major trade route fed by coastal commerce for centuries before contact (Graham, 2011; Sharer, 1996). The combination of farming and hunting/gathering would have required a diversity of tools and hunting gear, respectively. Maya who hunted in jungle ecosystems used bows and arrows, spears, blow guns, and traps (Redfield and Villa Rojas, 1964; Sharer, 1996) to secure various types of game, which included deer, tapir, agoutis, rabbits, monkeys and birds (Sharer, 1996). Milpa, or swidden (aka slash and burn), agriculture required tools to both clear bush for crops and to plant crops. Land was generally cleared with flint blades and axes, and crops were planted with digging sticks (Redfield and Villa Rojas, 1964). Travel was done on foot or via river systems in canoes. It should be noted that even though Tipu has a Colonial Period component, and the Spanish introduced metal tools to the Maya, the archaeological record suggests metal tools never took hold at Tipu (Graham, 1991; 2011). Therefore it is assumed that Colonial Period Tipu Maya would have primarily used flint tools as well, which required relatively more time and effort when used to clear bush than metal tools do (Sharer, 1996).

Since there was no single, dominant Maya center governing all settlements in the Lowlands (Cecil, 2009b; Jones, 1989; 1998; LeCount, 2001; Masson, 1997; 1999; 2000a), and as mentioned above, these centers would have expected different forms of tribute, there was also regional variation in the tribute systems that structured the lives of both elites and non-elites (Sharer, 1996). All elite sites considered in this study were part of the same "power network" which is thought to have been controlled by the most powerful centers in the Petén region of Guatemala (Ashmore and Sabloff, 2002; Audet, 2006; Ball and Taschek, 2004). While the Belize River Valley was characterized by shifts in power among its major centers from the Preclassic to Terminal Classic (Leventhal and Ashmore, 2004), lack of archaeological differentiation among elite sites in the Belize River Valley suggests minimal variation in the nature of the region's hierarchies (Audet, 2006). Maya communities (elite and non-elite) in the Roaring Creek, Caves Branch and Macal River Valleys were also connected to these major centers of the Belize River Valley via political and economic networks (Awe, 1998; Helmke, 2006; Isihara, 2000; Moyes, 2008). In sum, the sites chosen for this study control for the influence of regional

political systems on the daily lives of Maya people. The elites represented were part of the same the political hierarchy and the non-elites represented were part of the same political and economic network.

The Tipu Burial Sample

Surveys in the early 1980s led to the discovery of Tipu. Excavations that began in 1986 uncovered one church structure, its associated plaza, and a total of 585 historic period burials (176 males, 119 females, 249 juveniles, and 49 adults of unknown sex) (Graham, 2011; Jacobi, 2000). Of these burials, a total of 24 females and 33 males were analyzed here for upper limb entheses development. Samples were limited because the 3D method employed requires good cortical preservation of an entire enthesis. Enteses with even slight taphonomic damage that altered surface topography could not be measured. No individuals under the age of 20, or over the age of 50 were analyzed. The church structure, often termed a *ramada* (or open) chapel, is close to the Macal River, on its west bank, above the modern floodplain. It is 23m long and 8m wide, with apsidal east and west ends, and 80cm thick walls that were plastered (Graham, 2011). Except for around the altar, where stone walls reached the ceiling, the north, south and west walls were likely about 1.5m high (Graham, 2011). The upper half of the church was made of a wood frame and thatched roof (Jacobi, 2000). The architectural style of the church is typical of mid 16th century church constructions and was likely built in the mid 1500s when Tipu was established as an *encomienda* and *visita* mission (Jacobi, 2000; Graham, 2011). In addition to the church, a rectangular plaza and several other Colonial Period structures that incorporated foundations of Late-Postclassic buildings were built on top of debris from Postclassic occupations (Graham, 1991). To the north of the church structure, there was an *atrio* (courtyard) and the foundation of a rectory (residence for visiting friars) (Graham, 2011).

The majority of individuals at Tipu were likely interred in and around the church structure continuously from the establishment of the mission in 1544 to at least 1638, when a major rebellion forced temporary abandonment and possibly the destruction of

the church (Graham et al., 1989; Graham, 2011). However, evidence that the northern courtyard was disturbed for later burials, after the church and its associated buildings had collapsed, indicates Tipuans continued using the cemetery throughout the 17th century (Graham, 2011), perhaps until the community was forcibly removed in the early 1700s (Graham, 2011; Jones, 1989). Average age at death for adults (determined from osteological age indicators) was 28.5 years (Danforth et al., 1997), so Tipu represents a relatively "young" burial sample.

European Catholic tradition dictated that individuals of higher status be buried inside the church walls, and those of highest status buried closest to the altar; people of lowest status were buried outside the church walls (Miller and Farriss, 1979; Muller-Wille, 1993). Regardless of status, all individuals were to be buried with their heads to the west and feet to the east (Jacobi, 2000; Jones, 1989; Miller and Farriss, 1979; Muller-Wille, 1993). At Tipu, males, females and juveniles were buried both inside the church walls (in what would have been the floor of the church) and outside the church walls in clusters to the north, west and south of the structure (Figure 3.2). All but a few individuals were buried in the "proper" orientation with their heads toward the west. Figure 3.3 summarizes the sample sizes of individuals analyzed here from each burial context. Both inside and outside the church walls, some commingling of human remains occurred when previous burials were disturbed to make room for new burials. Disturbance is most pronounced at the back of the church inside the walls, and the burials that were lined up along the altar exhibited the least amount of commingling (Jacobi, 2000).

Figure 3.2: Tipu Site Diagram (created by Justin Sabino) (arrows indicate the direction of individuals' feet)

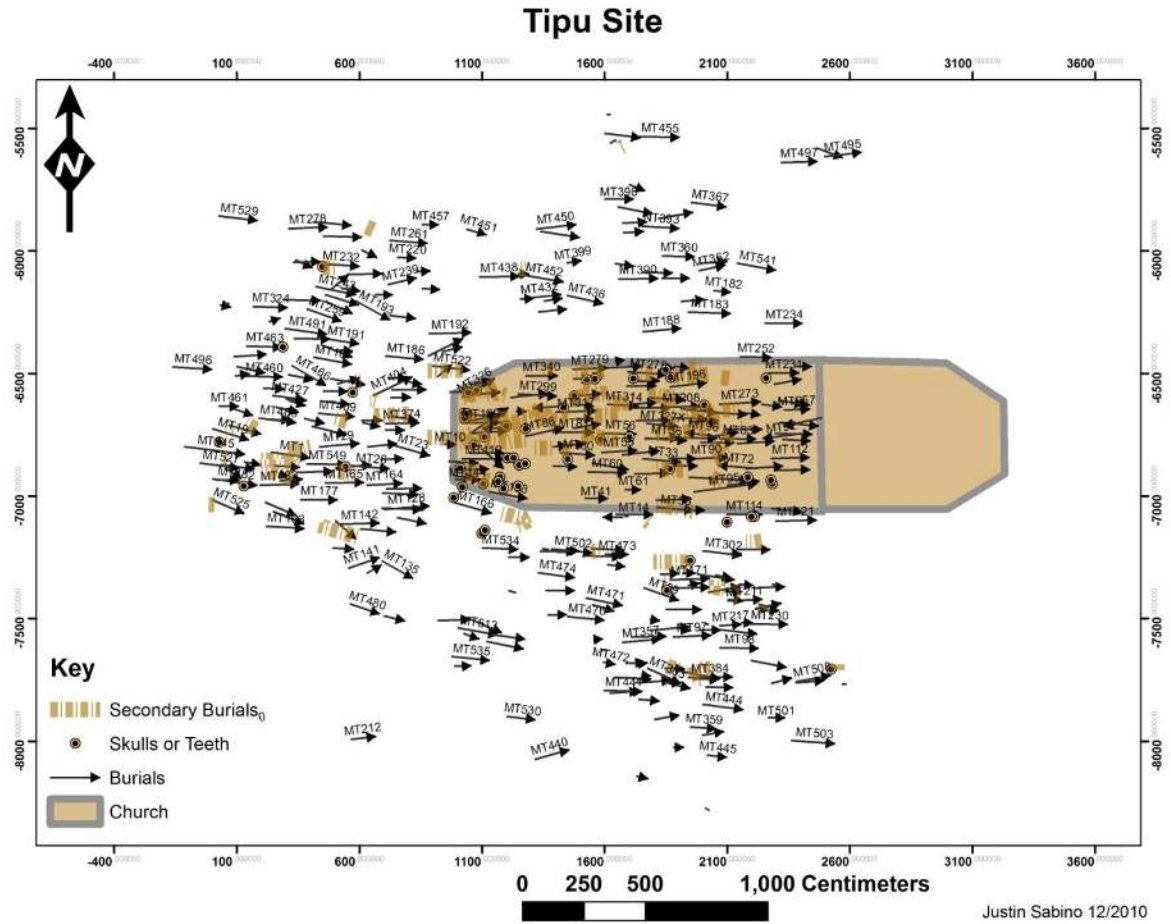
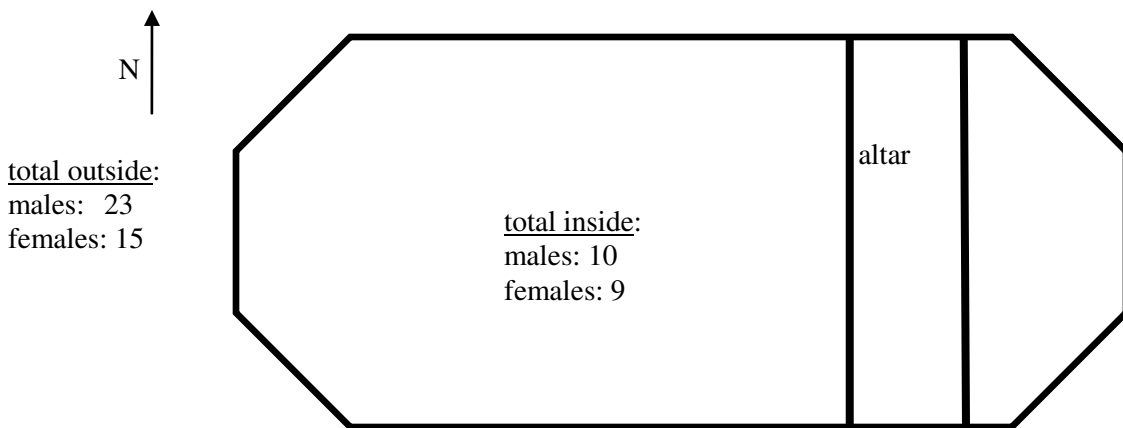


Figure 3.3: Schematic of Tipu Church Structure and Sample Sizes from each Burial Group (not to scale)



Non-metric dental traits and dental metrics previously analyzed for all individuals in the Tipu burial sample, are indicative of a relatively homogenous population (Jacobi, 2000). There is no evidence of Spanish admixture, and no Europeans were buried in or around the church. While most individuals were buried in simple shrouds, the few coffin burials that do exist near the altar also have dental characteristics typical of native Central Americans (Jacobi, 2000).

The skeletal sample at Tipu exhibits low prevalence of chronic infections, nutritional deficiencies, and trauma due to interpersonal violence (Cohen et al., 1994b; Danforth et al., 1997; Jacobi, 2000). Skeletal signatures of nutritional deficiencies or illness (e.g. porotic hyperostosis) and stature do not vary significantly between individuals buried inside and outside the church walls (Cohen et al., 1989; Cohen et al., 1994b; Jacobi, 2000), and general long bone robusticity is also relatively homogenous among the burial clusters at Tipu (Cohen et al., 1989; Wrobel, 2003). Therefore, in addition to lack of differentiation by health indicators, there is little variation in body size among burial groups at Tipu that may be indicative of differential health or nutrition.

No mass graves are evident, so there is no evidence that epidemics were so severe that many people died all at once (Jacobi, 2000). Colonial documents and census data from 1618 to 1697 do suggest dramatic population fluctuations in a time period contemporary with disease outbreaks, and population reductions were likely influenced by disease epidemics that killed susceptible individuals rapidly (Graham et al., 1989; Jacobi, 2000). However, reported fluctuations in Tipu's population were also influenced by: 1) inaccuracy of historical records 2) influxes of Maya who were fleeing Spanish colonization efforts in northern Yucatan, and 3) the tendency of indigenous people to abandon even the least heavily controlled missionized towns for un-colonized regions of the frontier zone (Farriss, 1984; Jones, 1998), especially during times of social upheaval and rebellions. In 1618, census records indicate the population of Tipu was 340 (Jones, 1989). In 1622, the population dropped to 30, but the very next year it was back to 340, and 20 years later the population was 1100 (Jones, 1989). It is uncertain whether the very low population in 1622 was due to an epidemic because it could also reflect inaccuracy in census documents or a dispersal event.

In relation to Maya communities that were forcibly relocated by reduction efforts and therefore under direct Spanish control (e.g. Lamanai), population size and health at Tipu was relatively well maintained (Danforth et al., 1997; Jacobi, 2000). In fact, the health and stature data from the Tipu burial sample are very similar to that of the pre-contact Petén Maya. Along with low incidence of anemia, this attests to Tipu's lower population size, and higher degree of isolation (Danforth et al., 1997). Nevertheless, it is important to keep in mind that Tipu was not a closed population (Danforth et al., 1997). The factors influencing the Tipu burial sample are considered in conclusions drawn.

Comparative Non-elite Samples

Caves Branch Rockshelter

Caves Branch Rockshelter (CBR) is located in the Caves Branch River Valley in the Cayo District of central Belize, which is characterized by rich alluvial plains, tropical forests and limestone ridgelines with hundreds of caves and rockshelters (Goldstein, 1996; Hardy, 2009). Rockshelters are distinguished from caves based on their exposed chambers and lack of a dark zone (Prufer, 2005; Peterson, 2006). To the west of Caves Branch River Valley is the Roaring Creek Valley, and to the south are the Maya Mountains (Hardy, 2009). Caves and rockshelters in both river valleys were used as early as the Preclassic and Early Classic for Maya cave ritual and burial practices (Wrobel et al., 2009).

All complete vessels recovered at CBR are of Late Preclassic form, and AMS dates on burials from several locations within the rockshelter indicate the interment of individuals at the site occurred from the Late Preclassic to the Late-Terminal Classic Periods (300 BC - AD 950) (Wrobel et al., 2009). Ceramics indicate that cultural deposits were made from the Middle Preclassic to the Postclassic (100BC - AD 1500) (Glassman and Bonor, 2005; Hardy, 2009). AMS dates and the relatively consistent degree of preservation of human remains suggest burials were not placed throughout the site's entire ceramic sequence (Wrobel, 2008; Wrobel et al., 2009). Prolonged use of a

particular cave or rockshelter over time is documented at other caves and rockshelters in western Belize (Peterson, 2006; Prufer, 2005), which suggests that despite any political change that occurred over time, such sites were always important, sacred places to the Maya (Hardy, 2009)

Excavations at CBR began in 1994 and continued until 2009 (Glassman and Bonor, 2005; Wrobel, 2008; Wrobel et al., 2007; Wrobel et al., 2009). Soils in the rockshelter have no clear stratigraphy, and artifacts, human remains and *jute* shells were found in varying concentrations in the majority of contexts, which signifies a long period of soil matrices being mixed by bioturbation and extensive use of the site for human burials (Glassman and Bonor, 2005; Wrobel, 2008). While there were some complete primary burials, they did not have discernible grave outlines and their headings varied (Wrobel, 2008). At CBR, this type of repeated use of the same area for interment suggests the burial sequence occurred over many generations, and in situ grave goods further suggest the cemetery was used during parts of two consecutive complexes that spanned ~1,000 years (Wrobel, 2008).

The human skeletal remains excavated from CBR represents a Classic period population of rural farmers (Glassman and Villarejo, 2005; Wrobel et al., 2007). The consistent non-elite status of individuals buried there over time is inferred from the presence of artifacts typical of a small farming community, which include: simply styled ceramic vessels, sherds from utilitarian vessels, net weights, local fauna, chert flakes and low frequencies of jadeite, obsidian and carved marine shell (Bonor, 2002; Wrobel, 2008; Wrobel and Tyler, 2006; Wrobel et al., 2007). There were no polychrome pot sherds, which were typically reserved for elite grave goods, included in burials (Wrobel, 2008). In addition, no elite presence is evident in the valley below the rockshelter until the Late Classic (AD600-800) (Andres and Shelton, 2010; Wrobel et al., 2007; Wrobel et al., 2009). This suggests that in the Caves Branch River Valley, patterns of cave use were not reflective of social status prior to this time period (Wrobel et al., 2009).

Wrobel and colleagues (2009) describe the skeletal sample from CBR as "relatively healthy" based on lack of severe infections, no evidence of trauma, little to no anemia and low caries rates. Both males and females and all age groups, including a large

percentage of infants, are represented in the burial sample, which is a demographic pattern typical of pre-industrial societies (Wrobel et al., 2007). A total of 37 individuals (18 females and 19 males) from the CBR burial sample met the preservation criteria for this analysis.

Actun Uayazba Kab (Handprint Cave)

Uayazba Kab is a cave site in the Roaring Creek Valley, in the side of a foothill to the west of monumental structures of Cahal Uitz Na. The valley is similar to Caves Branch Valley in its topography, ecology, and high frequency of caves (Jordan, 2008). The cave entrance is a rockshelter with twin entrances that are separated by a stalagmite column (Griffith, 1999). Ceramics indicate Late Preclassic (300 BC) use of the cave, but mortuary practices within the cave intensified in the Late Classic. A minimum number of seven individuals were recovered in the Burial Alcove of the cave, three of which were adults (Ferguson and Gibbs, 1999; Gibbs, 1998). Of the three adults, two females were well enough preserved for analysis in this study: Burials 3 and 4. All human remains were recovered in the Main Entrance chamber below the ground surface and associated with many grave goods including: shell, obsidian, quartz crystal, pyrite, slate, ceramics and lithic material (Gibbs, 1998). These grave goods, lack of cranial and dental modification, and the site's similarities to other rockshelters used for mortuary ritual, suggest individuals buried in Actun Uayazba Kab were non-elites (Wrobel, 2012b). The cave is unique in that it contains one of the most prolific examples of Maya cave art in Belize, which includes pictographs (including negative handprints), petroglyphs, sculpted anthropomorphic faces, and architectural carvings (Bassie-Sweet, 1991; Gibbs, 1998; Helmke and Awe, 1998). Most individuals were buried in flexed positions in simple pits or crypts. The Burial Alcove was likely the primary location for burials because of its interior location and its deeper soil matrix

Comparative Elite Samples

The elite status of individuals was determined based on their association with monumental architecture, elaborateness of grave goods, and/or placement in caves that are associated with major centers. The majority of the elite sample used here actually comes from a cave context, which is mostly reflective of differential preservation in the Lowlands. Skeletal remains in dry caves and rockshelters are always best preserved, even when considering individuals buried in tombs built in to monumental structures, because the humidity of the region cannot be combated by built structures. Both Maya elites and non-elites honored their ancestors by interring them within architectural features, whether they were residential house mounds or the monuments of major centers. It is thought that this facilitated social definition of one's residence, and for elites, it additionally reinforced an individual's political power, status, and ties to a major center (McAnany, 1998).

For the purposes of this study, i.e. defining a sample of Maya elites that can be compared to individuals at Tipu in order to assess activity patterns in the Colonial Period, it is assumed that all individuals from Baking Pot, Cahal Pech, and Je'reftheel are elites. However, it is important to consider that grave goods do not always equal social status and several lines of evidence should be used when inferring status. For individuals at Baking Pot and Cahal Pech, this assumption is based on the association of burials with monumental architecture and elaborate grave goods, as well as the status of those sites as major centers of the Belize River Valley during the Late to Terminal Classic Periods (AD 580-900) (Audet, 2006). It should be noted that two individuals analyzed from Baking Pot are considered simple burials with very few grave goods and no evidence of tomb structures. Preliminary tests were conducted to determine whether the three elite samples differed significantly from one another in skeletal robusticity, and no significant differences in entheses surface area were detected between males or females for any entheses of the humerus, radius or ulna (see Results).

The assumption that Je'reftheel cave burials represent elites may also be problematic. Presumably, Maya individuals of all social tiers saw caves as sacred places due to their association in Maya mythology as entrances to the underworld (Griffith,

1999; MacCleod and Puleston, 1978; Prufer, 2005; Prufer and Brady, 2005; Saul et al., 2005). Xibalba is the Maya underworld described in the Popul Vuh. It is depicted as a watery, dark level of the universe. Caves symbolized entrances to this mythological realm (Griffith, 1999; MacLeod and Puleston, 1978; Prufer, 2005). It has also been argued that various cave chambers served as analogs to the multiple "houses" that occurred in the underworld (Tedlock, 1985). Because they were so revered, caves were used by many for religious ceremonies associated with ancestor veneration, birth, death, fertility, and spiritual transformation (Awe, 1998; Bassie-Sweet, 1991; Rissolo, 2003; Stone, 1997; Vogt and Stuart, 2005; Prufer, 2005). However, there is also evidence that certain cave sites came to have more specific meanings and functions among the Maya (Brady and Prufer, 2005; Garza et al., 2002; Glassman and Bonor, 2005; Peterson, 2006; Prufer, 2005; Saul et al., 2005), and there are several lines of evidence that Je'reftheel was a cave primarily used for elite mortuary practice.

Je'reftheel is proximate to the recently documented and highly integrated major centers of Tipan Chen Uitz and Cahal Uitz Na in the Roaring Creek Valley (Andres et al., 2010; Conlon and Ehret, 1999; Jordan, 2008; Wrobel, 2011). Both of these major centers emphasized and intensified cave ritual during the Late Classic (Andres et al., 2010; Conlon and Ehret, 1999; Jordan, 2008), when Je'reftheel was primarily used for mortuary ritual (Helmke, 2009; Helmke et al., 2012). At Tipan Chen Uitz, the significance of caverns under constructed buildings was emphasized by their use as caches for elaborate prestige items, and at Cahal Uitz Na, a *sacbe* (constructed road) connected the dominant elite residence to a small ritually significant cave (Andres et al., 2010). These major centers were integrated socially, politically, and economically via *sacbeob* (multiple constructed roadways) (Andres et al., 2011a; Wrobel, 2011) and represent a network of elites with close ties to the subterranean parts of the Caves Branch and Roaring Creek Valleys (Andres et al., 2010), which included Je'reftheel. Ethnographic and ethnohistoric accounts provide evidence that cave ritual was a means for individual or corporate groups to claim ties with the land (Jordan, 2008), and that these claims to subterranean sites, symbolic of the underworld, became status-related in the Late Classic (Andres et al., 2011b). It is thought that because newly-arrived elites would not have had longstanding

claims to the region, they used the caves there extensively for burial and other rituals as a way to legitimate their newly established political claims to the region (Jordan, 2008). The restricted nature of the cave, artifacts included in burial contexts, and skeletal evidence that individuals at Je'reftheel represent a small family or corporate group, also support the assumption that high status individuals were interred there (Helmke et al., 2012; Wrobel, 2011).

Je'reftheel (Skeleton Cave)

Je'reftheel is a small cave in the eastern hills of the Roaring Creek Valley, in an area known as the southern Roaring Creek Works (Helmke, 2009). It is one of several caves in the area that contain evidence for a coherent regional tradition of cave utilization, however, the nature of its use suggests it was part of the mortuary ritual of a distinct community (Helmke et al., 2012). Most features include commingled human remains, suggesting mortuary behavior similar to that seen in tombs, where individuals were collected and re-deposited (possibly from other locations) or disturbed to make room for more recent interments (Tiesler, 2007; Wrobel, 2011). The commingling of remains in some areas of the cave may also be due to water activity (Wrobel and Ebeling, 2010). Skeletal remains show no indication of violence or sacrificial practice, and seem to represent a small corporate or family group, based on similarities in cultural modifications and a high rate of congenitally absent 3rd molars (Wrobel, 2011). Strontium isotope analysis indicates they were residents of a nearby site (Wrobel, 2011).

The cave is a single narrow passage that widens into several alcoves and terminates in several chambers (Helmke, 2009). Within the site, 12 distinct features were defined in the 2004 field season, and seven of those contained human remains (Helmke, 2009; Wrobel and Ebeling, 2010; Wrobel, 2011). Of the seven features that include human remains, six provided skeletal material suitable for this study representing 14 females and 22 males. These Features are 1, 4, 5, 6, 7, and 11. All archaeological features at Je'reftheel seem to have been deposited over a short time period (~100-150 years) in the Late Classic (AD550-950), and the cave's primary use was for mortuary practice

(Helmke, 2009; Helmke et al., 2012). Whole ceramic *ollas* of consistent form were the most frequent artifact deposited, and also support the Late Classic date (Helmke, 2009; Wrobel, 2011). Small congregations of people were possible only in Chambers 1 and 2 near the mouth of the cave. This is reflected by larger clusters of artifactual features in these chambers (Helmke et al., 2012). The cave's termini were the preferred places for interment of human remains and very restricted passage ways to these locations would have allowed placement of bodies by only one or a few individuals (Helmke, 2009; Helmke et al., 2012).

Features 1 and 4 (MNI=4) are scatters of disarticulated human remains in Chamber 2. Feature 5 (MNI=6) is a well-preserved group of commingled remains in Chamber 3 associated with a small ceramic *olla*, carved shell *adornos*, a stemmed chert biface, carved shell L-shaped ear adornments (labrets) with greenstone appliques, and two concentrations of perforated Dwarf Olive (*Olivella*) shell tinklers that formed part of a belt and a bracelet. The labrets, bracelet and belt were found *in situ* with a relatively intact burial. Belts of Olive shell tinklers are commonly represented in Mayan hieroglyphics (Helmke et al., 2012; Wrobel, 2011). Similar artifacts have been found in main burial chambers at Actun Kabul and Actun Tunichil Mucnal, and in special deposits at Pook's Hill (Helmke et al., 2012). Features 6 (MNI=1) and 7 (MNI=3) are clusters of fragmentary human remains interspersed with small ceramic sherds in Alcove 1, and Feature 11 (MNI=1) is a group of scattered human remains and two *ollas* in Chamber 1 (Helmke, 2009). Both males and females, as well as adults and juveniles are represented at Je'reftheel, so there seem to be no restrictions on social groups defined by sex or age interred there (Wrobel, 2011).

Baking Pot

Baking Pot is located on the south bank of the Belize River between the modern towns of San Ignacio and Belmopan, only 10 km away from the site of Cahal Pech (Helmke and Awe, 2008). The site is marked by several core monumental structures and plazas, and monumental groups that are connected by causeways (Helmke and Awe,

2008), as well as hundreds of peripheral smaller monumental structures, administrative buildings and residential structures (Audet, 2002; Audet and Awe, 2004). The site was occupied from the Middle Preclassic (~600-300 BC) into the Early Postclassic (AD1200) (Hoggarth et al., 2008; Audet, 2006), and it served as capital of a small kingdom from AD 250-830 (Hoggarth et al., 2008).

A total of four individuals from the site were preserved well enough for analysis in this study. The features they were associated with include: Structure 209 and Plaza 2 in Group 1, and Structure 190 in Group 2. Groups 1 and 2 are connected by a causeway, and at the north end of the causeway in Group 1 is Structure 209, which is associated with two monolithic limestone altars and a fragmentary plain limestone stela (Helmke and Awe, 2008; Audet, 2006). Plaza 2 of Group 1 consists of two pyramidal structures, 5 range structures, 2 ballcourts and a platform (Helmke and Awe, 2008). Another causeway leads south from the southwest corner of Group 2 and at its southernmost terminus is Structure 190, which is associated with two plain limestone stelae and a masonry altar that had been covered by more recent construction activity (Helmke and Awe, 2008; Audet, 2006). Structures B1-B4 define the main plaza of Group 2. Along with Structure B3, Structure B4 defines one border of Ballcourt 3 (Helmke and Awe, 2008). Below are descriptions of burials analyzed and their associated structures.

Group 1 Burials:

Structure 209, Burials 3 and 4

Structure 209 includes components dated from the Late Preclassic to the Late Classic (100 BC - AD800) (Audet, 2006). A total of four people were interred in Structure 209 along the central axis of the platform at its summit (Audet, 2006), but only two individuals, Burials 3 and 4, were preserved well enough for analysis. The structure was made of cut limestone blocks, had plastered floors, and was characterized by a series of elliptical terraces topped with a platform that is similar to platforms dating to the Preclassic known to have been used as spaces for ritual dancing. A short staircase allowed access to the platform from the causeway. Like many Classic period ceremonial complexes, the structure had two altars and a single broken stela.

Burials 3 and 4 were interred in the same small tomb, at the center of the uppermost platform, approximately 3m below the most recently constructed floor of Structure 209. Ceramics within the tomb indicate that the burials date to the Late Classic period (AD 550-650) Burial 3 was a primary burial of a middle adult male (35-50 years at death) placed in an extended position and Burial 4 was a secondary burial. Burial 4 is a partially complete skeleton whose elements were grouped together and placed in a polychrome dish within the tomb at the feet of Burial 3 (Audet, 2006). Grave goods associated with this tomb include: seven vessels, bone hairpins, jade objects including pendants and ear flares, and three obsidian blades (Audet, 2006).

Group 1 Plaza 2, Burial 1

Plaza 2 in Group 1 is bordered on the east and west by two large temples, designated Structures E and B, respectively (Swain, 2005). Burial 1 was uncovered in a 1.5m x 1.5m unit that was laid out along the central axis of Structures E and B. The burial was under three subsequently constructed floors and is considered a "simple" burial, since no large stones encased it (Swain, 2005). Skeletal remains are those of a young adult male (20-35 years at death) placed in a semi-flexed position. The individual's maxillary incisors and canines each have one round jade inlay. Ceramics associated with the individual suggest a Late Classic Period (AD 590-880) interment (Swain, 2005).

Group 2, Structure 190, Burial 2

Structure 190 formed the southern terminus of Baking Pot's southernmost causeway and its last two construction phases are dated to the Late and Early Classic. The structure was a low platform with a large central altar and a two-room masonry structure made of cut limestone blocks that were mortared together and covered with lime plaster. During Late Classic construction, four individuals were interred within Structure 190 along its central axis (Audet, 2006). Burial 2 is the only burial that fit analysis criteria, and is an adult male of unknown age who was interred with two unslipped ceramic bowls (Audet, 2006).

Cahal Pech (Place of Ticks)

Cahal Pech was a hilltop community at the junction of the Mopan and Macal Rivers, on the west bank of the Macal River, and was made up of several temples, plazas, courtyards, administrative and residential structures, and two ballcourts (Audet, 2006; Garber et al., 2004). Possibly one of the first occupied centers in the Belize Valley, construction began at Cahal Pech in the Preclassic and building activities continued in the Early and Late Classic. Social and political ties to Baking Pot are evident from ceramic assemblages (Audet, 2006). Three individuals interred here were analyzed.

Tolok Burials 2, 4(Individual 2), and 5

The Tolok Group is on the periphery of Cahal Pech's site core. It consists of a group of mounds on a long narrow ridge (Powis, 1992). Ceramics indicate it was occupied from the Preclassic to the end of the Late Classic. Burial 2 was one of five primary burials placed next to a circular Preclassic platform ~5m in diameter. Interment likely occurred in the Late Classic (Powis, 1992). Burial 2 was a capped cist grave and represents a young adult male (Powis, 1992; Song, 1992). Associated grave goods included shell pendants and a polished jade disk (2cm in diameter). Burial 4 was a simple cist grave that contained two individuals. Individual 1 was placed on top of Individual 2, which had the best skeletal preservation (Powis, 1992). Individual 2 is a middle adult male. Burial 5 was also a simple cist grave containing a middle adult male (Powis, 1992).

Methods

The sex and age of each individual analyzed was estimated using techniques described by Bass (1995) and Buikstra and Ubelaker (1994). Pelvic features examined to estimate sex include: the sciatic notch, ischio-pubic ramus, and sub-pubic angle. Skull attributes were used in conjunction with, or in place of, pelvic indicators of sex. These include the relative robusticity features at glabella, the nuchal region, the mental eminence and the mastoid processes. When skeletal elements indicative of sex were too

fragmentary or absent, discriminant functions were used to estimate sex from long bone robusticity measurements (Wrobel et al., 2002) (See Table 3). These discriminant functions were developed using the Tipu burial sample (Wrobel et al., 2002). Wrobel and colleagues (2002) created functions for more single measurements than listed below, but not all were possible to make on the more fragmentary samples analyzed here. The sex of individuals for which these types of estimates were made was also confirmed using multivariate discriminant functions available at ibetsy.com/bones (Wrobel et al., 2002).

Table 3.3: Single measurements used to estimate sex following discriminant functions created by Wrobel and colleagues (2002)

Element	Measurement
Femur	Subtrochanteric AP diameter Midshaft AP diameter Midshaft circumference
Tibia	AP diameter at nutrient foramen Midshaft AP diameter Midshaft circumference Minimum circumference
Humerus	Midshaft maximum diameter Midshaft minimum diameter Midshaft circumference Deltoid tuberosity diameter Minimum circumference
Radius	Minimum circumference Tuberosity diameter
Ulna	Minimum circumference

The pubic symphysis and auricular surface were the primary skeletal features consulted to estimate age, using the Suchey-Brooks Scoring System (Brooks and Suchey 1990) and Ubelaker's (1989) auricular surface descriptions, respectively. In absence of os coxae, cranial suture closure and tooth wear were considered. Only young (20-35 years) and middle adults (35-50 years) are represented in skeletal samples analyzed. Since the majority of skeletons were not complete enough to narrow down age ranges, individuals were placed in one of these two general age categories.

Estimates of body size were also made for individuals in this study when possible, since body size effects expressions of bone functional adaptations (Ruff et al., 1991). Even though this trend is better documented for the cross-sectional properties of long bones (Ruff, 2008), it is also necessary to test for the effects of body size on entheses surface area (Weiss, 2004). When possible, femur, tibia and/or humerus length were

measured to estimate stature with formulae developed from a Mesoamerican reference sample (Genoves, 1967), which is the most relevant sample available for pre-contact and Colonial Period Maya populations. Body mass was estimated using discriminant functions created with a pre-historic Native North American reference sample (Daneshvari, 2009) (Table 3.4), as well as with the more traditionally used femoral head diameter (Ruff et al., 1991).

Table 3.4: Measurements for estimating body mass using Daneshvari's (2009) discriminant functions

Measurements for females	Measurements for males
ML width of femoral midshaft	Femur length
Femoral head diameter	Femoral bicondylar breadth
Humerus epicondylar width	Tibia maximum midshaft diameter
Femur length	

3D Image Acquisition

A Nextengine® 3D laser scanner was used to acquire images of all entheses (Table 3.1) for each individual in this study. Elements scanned for this study included the humerus, radius, and ulna (both rights and lefts). First, all osteometric measurements described above were made. For better digital visibility, muscle insertion site margins were highlighted with chalk. Entesis margins were determined visually, under strong light, with no magnification. Chalk was placed on the normal smooth cortex just outside the irregular, rugose and/or upraised cortex of insertion sites so that surface area measurements (described below) taken from the innermost border of the chalk outline captured all surface topography present. Once all entheses were chalked, each long bone was mounted on the laser scanner's turntable.

The turntable was placed 6" in front of the scanner and long bones were positioned using the reference camera window in Nextengine's® Scan Studio HD® software (2006-2010) so that all relevant features were visible to the laser scanner (Figure 3.4). The scanner was set to macro mode and points per square inch were set to the high definition (HD) range (resolution: 0.127mm). Eight divisions were used for all scans, which means for each 360° turn of a long bone the scanner captured eight 3D images of the bone's surface. These eight scans were then "stitched" together to create a 3D

reconstruction of the bone using Scan Studio. Finally, images were "cleaned up" by eliminating parts of the turntable and arm that were captured in the scan, and using the Fuse option to eliminate image distortion caused by having several overlapping scans of each long bone's surface. The Fuse option matches up the shared data points in each of the eight scans to create a smooth, aggregate 3D image. After editing, all 3D images were stored on external hard drives for further measurements.

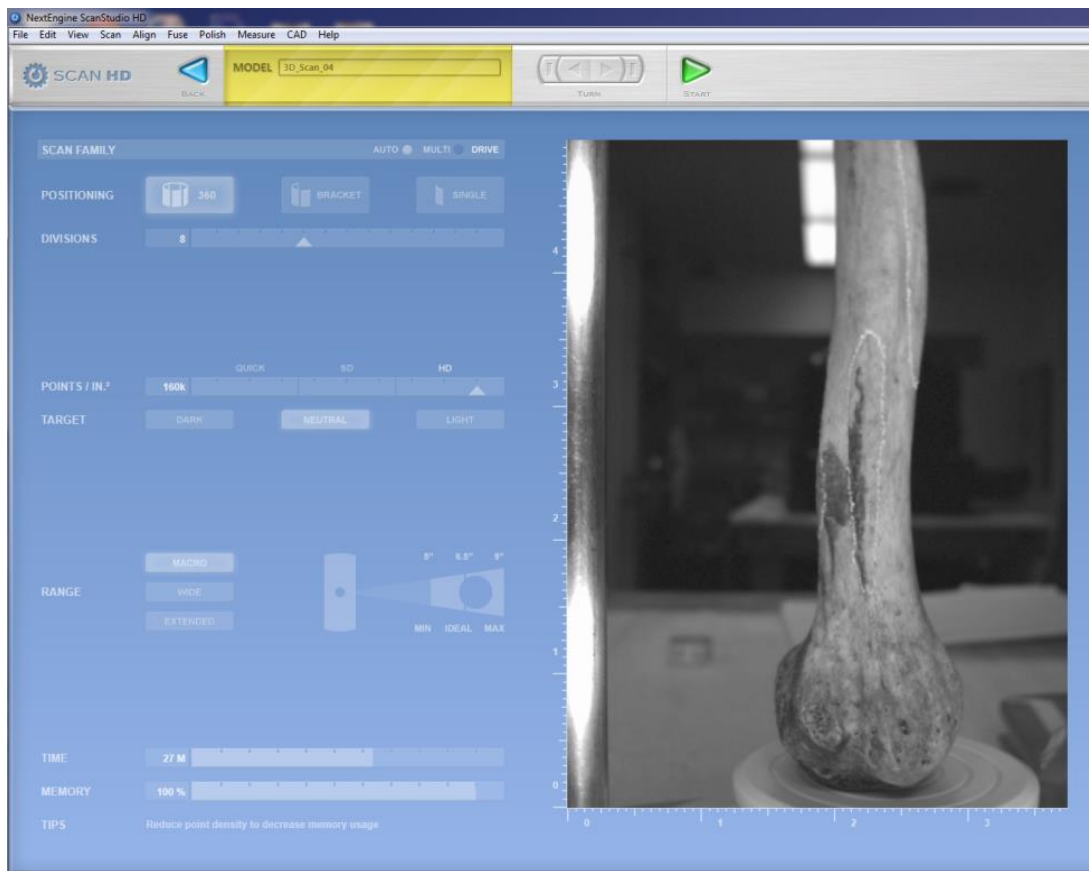


Figure 3.4: Example of ScanStudio's Acquisition Window and Chalked Entheses Enthesis Surface Area

Using the same ScanStudio HD software, each humerus, radius, and ulna image was cropped so that only images of each element's entheses within chalked outlines remained (Figure 3.5). Using the polygon tool in the Trim window, points were set down along the innermost border of each chalked outline to trace the organic shape of each

entheses and to designate the parts of each image to be eliminated. After trimming, the surface area (cm²) of each enthesis was measured with ScanStudio's surface area tool.

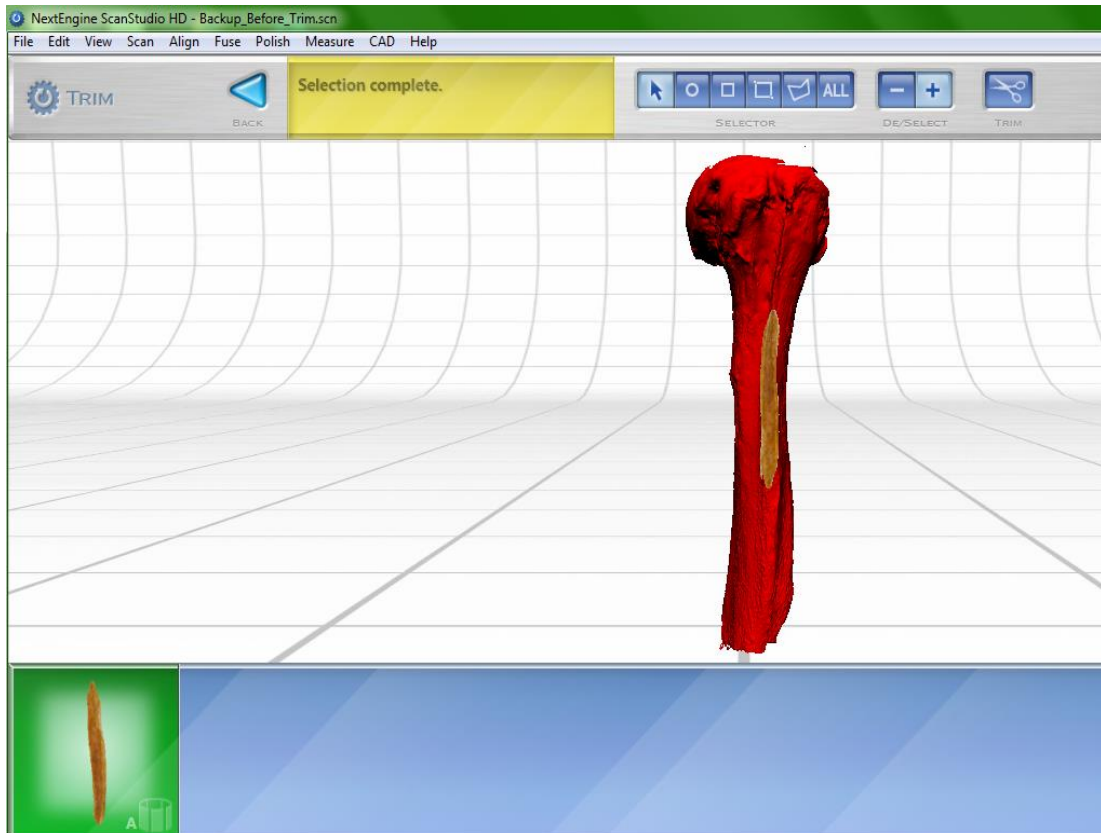


Figure 3.5: Example of Trimming Image for Measurement of Pectoralis Enthesis Surface Area

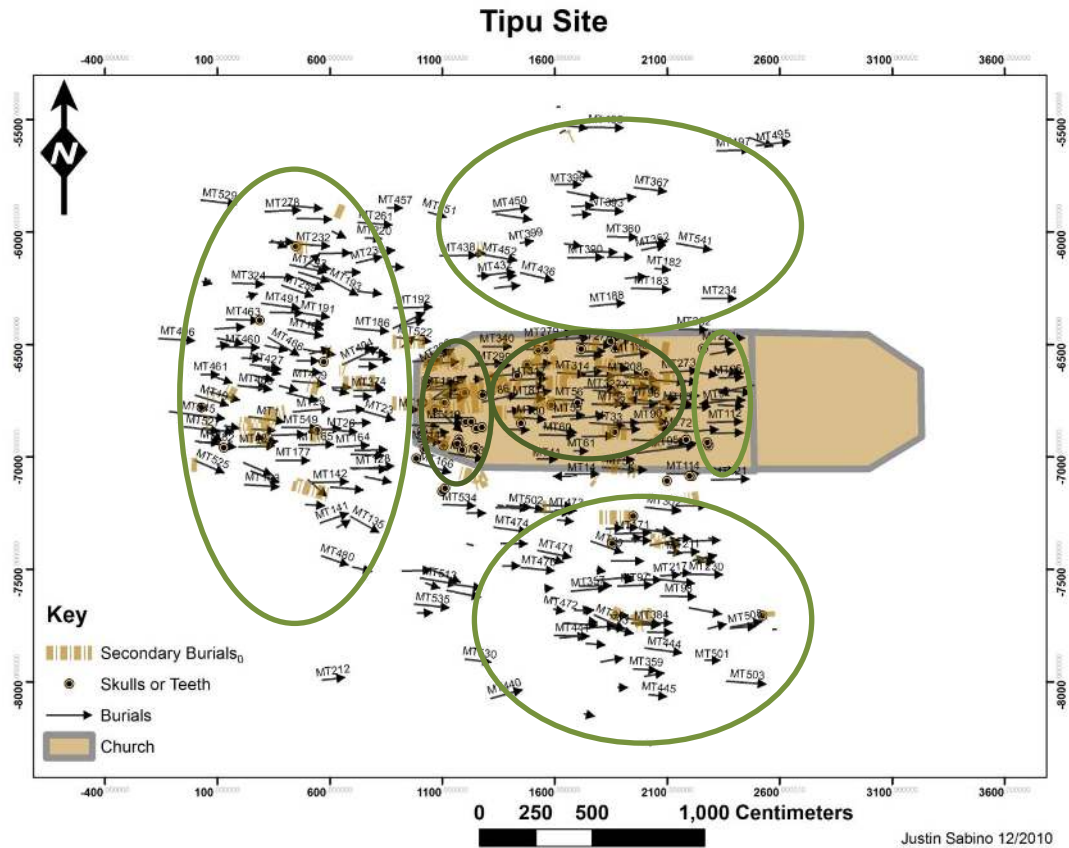
The Nextengine® scanner is not programmed to take measurements using the metric system, so once surface area measurements were recorded, they had to be converted from square inches to square centimeters using the following equation: $1 \text{ in}^2 = 6.4516 \text{ cm}^2$. Because this method of quantifying enthesis development is very new (Nolte and Wilczak, 2010; Noldner and Edgar, n.d.), intra-observer error was assessed for each enthesis. Images from a sample of 20 individuals from Tipu were cropped and measured for a second time, as described above, and percentage error was calculated from differences between first and second surface area measurements. For all seven entheses, error rates ranged from 4-8%.

Statistical Analyses

Spearman's Rho correlations were first used to test for effects of body size on entheses surface area. Body mass and stature estimates, as well as basic osteometric long bone dimensions, were compared to surface areas measured for each enthesis (both rights and lefts) to determine whether any surface area correlated significantly with measures of body size. Within each burial group (Tipu, elites and non-elites), Mann-Whitney U tests were used to detect significant differences in entheses surface areas: between young adults and middle adults to test for effects of age; between right and left elements to detect asymmetry; and between the males and females to test for sexual dimorphism.

The three hypotheses presented above were tested in the following way. Individual value plots that included all burial groups (elite, non-elite, and Tipu) were first inspected for patterns of variation in entheses surface areas among skeletal samples. One-way ANOVA was used for initial detection of which entheses differed significantly among burial groups. Mann Whitney U tests were then used to determine whether observed differences were significant among burial groups. These tests were done using both general and specific Tipu burial groups. General burial groups at Tipu are those inside the church structure and those outside the church structure. Specific burial groups were designated to investigate variation among burial locations at Tipu in more detail. Specific burial groups inside the church included: inside the church at the front where there is a row of burials bordering the altar, a cluster of burials inside the church at the center of the nave, and a cluster inside the church walls at the back of the nave. Specific outside burial groups include clusters to the north, west and south of the church structure (Figure 3.6). Individual value plots were performed in Minitab 15 (2007). All other statistical analyses listed above were performed in SAS 9.2 (2009). It should be noted that due to small sample sizes, not all specific burial groups at Tipu are represented in each analysis, and t-tests had low statistical power (0.41-0.50).

Figure 3.6: Tipu Site Diagram with Specific Burial Clusters Indicated



To further investigate patterns of entheses development among burial groups, entheses surface areas for all burial groups were analyzed with Principal Component Analysis (PCA) and Cluster analysis in PAST version 2.16 (Hammer et al., 2001). Euclidean distances among variables were specified for PCA. Clustering was done with unweighted pair-group averages (UPGMA). Both analyses were performed using the surface areas of each of the seven entheses from the following burial groups: non-elites, elites, and the general burial groups inside and outside the church at Tipu.

Results

Tests for the Effects of Body Size and Age

Spearman's Rho correlations detected very few significant effects of body size on enthesis surface areas for males or females (Tables 3.5-3.9). The majority of correlations between any enthesis and femoral antero-posterior (AP) midshaft diameter, tibial AP midshaft diameter, and humeral maximum midshaft diameter were not significant. No correlation coefficients for osteometrics and surface areas exceeded 0.65 for males or females. The only exception is that tibia AP midshaft measurements correlated significantly with brachialis surface areas (Table 3.7). There were also very few significant correlations between enthesis surface areas and body mass and stature estimates. Therefore, surface areas were not standardized by body size and absolute surface areas were used in all subsequent analyses. Only surface areas for the left deltoid for males, and the left teres major for females correlated significantly with body mass estimates. The lack of strong correlation between upper limb enthesis surface areas and body size is not surprising because lower limb entheses have been shown to have higher correlations with body size (Weiss, 2004).

Table 3.5: Spearman Correlation Coefficients for Enthesis Surface Areas and Osteometrics - males and females combined (total sample; right elements only) n=38

	Deltoid	Teres	Pectoralis	Biceps	Pronator	Brachialis	Supinator
Femur AP midshaft diameter	0.16	-0.04	0.51	0.20	0.02	0.29	-0.17
Tibia AP midshaft diameter	0.20	0.28	0.23	0.40	-0.12	0.02	-0.10
Humerus max. midshaft diameter	0.001	0.174	0.06	0.20	0.16	-0.11	0.04

* indicates significant correlation coefficients

Table 3.6: Spearman Correlation Coefficients for Enthesis Surface Areas and Osteometrics - females (total sample; right elements only) n=15

	Deltoid	Teres	Pectoralis	Biceps	Pronator	Brachialis	Supinator
Femur AP midshaft diameter	-0.22	-0.26	0.17	0.25	0.22	0.01	-0.45
Tibia AP midshaft diameter	-0.28	-0.21	0.22	0.38	0.65	0.25	-0.59
Humerus max. midshaft diameter	0.009	0.15	-0.47	-0.04	-0.42	0.17	0.42

* indicates significant correlation coefficients

Table 3.7: Spearman Correlation Coefficients for Enthesis Surface Areas and Osteometrics - males (total sample; right elements only) n=17

	Deltoid	Teres	Pectoralis	Biceps	Pronator	Brachialis	Supinator
Femur AP midshaft diameter	-0.25	0.03	-0.26	0.25	-0.46	-0.05	-0.54
Tibia AP midshaft diameter	-0.03	0.64	0.11	0.74	-0.55	0.75*	0.03
Humerus max. midshaft diameter	-0.03	-0.10	-0.17	0.28	-0.14	0.06	0.006

* indicates significant correlation coefficients

Table 3.8: Spearman Correlation Coefficients for Enthesis Surface Areas and Body Size - males (total sample) n=33

	Deltoid		Teres		Pectoralis		Biceps		Pronator		Brachialis		Supinator	
	R	L	R	L	R	L	R	L	R	L	R	L	R	L
BM	-0.041	0.57*	0.25	0.20	0.31	0.12	0.16	0.46	-0.19	0.45	0.53	0.11	0.25	0.75
Stat	-0.045	0.34	0.10	0.04	-0.17	0.10	0.46	0.42	-0.35	0.50	0.35	0.14	0.28	0.28

-body mass estimates from femoral head diameter (Ruff et al., 1991)

-stature estimates from Genoves (1967) formulae (femur or tibia length)

* indicates significant correlation coefficients

Table 3.9: Spearman Correlation Coefficients for Enthesis Surface Areas and Body Size - females (total sample) n=24

	Deltoid		Teres		Pectoralis		Biceps		Pronator		Brachialis		Supinator	
	R	L	R	L	R	L	R	L	R	L	Right	L	R	L
BM	0.25	0.22	0.66	0.72*	0.08	0.23	0.48	0.20	0.09	0.75	-0.05	0.50	0.20	0.48
Stat	0.03	0.48	0.09	0.21	0.28	0.01	0.34	0.31	0.15	0.40	0.46	0.14	0.19	0.09

-body mass estimates from femoral head diameter (Ruff et al., 1991)

-stature estimates from Genoves (1967) formulae (femur or tibia length)

* indicates significant correlation coefficients

Mann Whitney U tests for significant differences between entheses surface areas of young and middle adult age groups produced no significant p-values (Table 3.10). Therefore, young and middle adults were combined for all subsequent analyses to maximize sample sizes. There were also no significant differences detected among elite comparative samples for any entheses (p-value range: 0.076-0.826).

Table 3.10: T-tests for effects of age on Entheses (males and females combined)

	Deltoid	Teres	Pectoralis	Biceps	Pronator	Brachialis	Supinator
p-value	0.405	0.103	0.149	0.715	0.418	0.075	0.977

Tests for significant differences between the surface areas of right and left entheses produced no significant p-values (p-value range: 0.062-0.982), and therefore no indication of asymmetry in entheses development for males or females within samples analyzed.

To maximize sample sizes further, right and left entheses were combined for all subsequent analyses.

Tests for sexual dimorphism in enthesis surface areas only indicate significant dimorphism within the Tipu burial sample for the pectoralis major ($p=0.020$), biceps brachii ($p=0.001$), and brachialis ($p=0.040$) insertions. No significant sexual dimorphism was detected within the elite sample, but it should be noted that elite females are under-represented. Non-elites only demonstrated significant sexual dimorphism in the biceps brachii enthesis ($p=0.010$). Nevertheless, male and female elites and non-elites were still analyzed separately to detect any differences in activity patterns between the sexes at Tipu.

Tests for Similarity in Enthesis Surface Areas Among Burial Groups

The following is a summary of One-way ANOVA and Mann-Whitney U test results for inter-sample comparisons (Appendix 1) and the results of PCA and Cluster analyses for each of the three hypotheses tested (Appendix 2). For all PCA presented here, the first and second components together account for 86-99% of the variability in surface areas for each enthesis. Due to the small sample sizes of burial groups compared, and therefore the low statistical power of Mann-Whitney U tests (described below), the discussion following this section is mainly interpretation of PCA and Cluster analysis results. Table 3.11 illustrates that even at a 10% level of significance, the small sample sizes of burial groups compared create relatively high risks of committing Type II errors. No statistical power calculated was greater than the acceptable value of 0.80 for 5% or 10% levels of significance. All t-tests were performed at both 95% and 90% confidence levels, however, tests at 90% confidence did not produce any additional significant results. T-tests and individual value plots were referenced when assessing which burial groups had higher or lower enthesis surface areas. All t-tests reported in the following sections are at the 95% confidence level.

Table 3.11: Statistical Power of T-tests

Comparison	alpha=0.05		alpha=0.10	
	Males	Females	Males	Females
Elites - Non-elites	0.32	0.25	0.43	0.36
Tipu: Inside-Outside	0.25	0.20	0.36	0.31
Tipu Inside - Elites	0.23	0.19	0.34	0.28
Tipu Outside - Elites	0.34	0.22	0.46	0.33
Tipu Inside - Non-elites	0.23	0.23	0.34	0.33
Tipu Outside - Non-elites	0.34	0.29	0.47	0.41

- power values attained from Piface 1.76 (Lenth 2006-2009)

Hypothesis 1: Pre-contact elite samples will have different patterns of upper limb entheses development than pre-contact non-elite samples.

Very few significant differences in entheses surface area between elite and non-elite samples were detected by t-tests. This is likely due to the relatively small sizes of samples compared and therefore low statistical power. Female elites and non-elites differed significantly in surface areas of the deltoid ($p=0.033$). However, PCA and Cluster analyses both indicated that elite and non-elite females were dissimilar in surface areas of all entheses: the deltoid, teres major, pectoralis major, biceps brachii, pronator teres, brachialis and supinator. This suggests pre-contact females of different social tiers engaged in different activities involving the upper limb, though perhaps not at a level detectable with these statistics and sample sizes.

There were also no significant differences in entheses surface area detected between male elites and non-elites (the lowest p-value was 0.066). PCA and Cluster analyses did not separate the pre-contact male samples as sharply as they did for females. Elite and non-elite males were most similar in surface areas for the deltoid, teres major, pronator teres, and supinator. Pre-contact males were dissimilar in surface areas of the pectoralis major, biceps brachii, and brachialis (Appendix 2).

In sum, hypothesis 1 is supported for females, but not for males. While elite and non-elite males exhibit different development of the pectoralis major, biceps brachii and brachialis, they have similar development of the deltoid, teres major, pronator teres and supinator.

Hypothesis 2: Upper limb entheses development will be homogenous within the Tipu burial sample.

Within the Tipu burial sample, there were largely no significant differences detected by t-tests in entheses surface areas among general or specific burial groups for females ($p=0.091-0.152$). The only exception is that development of the pronator teres, which is active in forearm pronation, was significantly greater among females in the outside northern burial cluster than that of all other females buried outside the church walls ($p=0.012$). PCA and Cluster analyses demonstrate that females from inside and outside burial groups cluster together for surface areas of the deltoid, teres major, biceps brachii, pronator teres, and brachialis. They were most dissimilar in development of the pectoralis major and supinator.

While t-tests also revealed no significant differences among Tipu burial groups for males ($p=0.085-0.099$), a couple notable, yet marginal p-values did result from a comparison of males in specific burial clusters at Tipu. Males from the burial cluster inside the church walls at the center of the nave tend to have greater mean pectoralis surface area than males in the burial cluster by the altar ($p=0.050$). Males from the burial cluster inside the church at the center of the nave, and males buried outside to the north of the church structure were also different, though not significantly so, in development of the supinator ($p=0.066$). PCA and Cluster analyses indicate males from inside and outside burial groups were similar in development of the deltoid, pectoralis major, biceps brachii, and brachialis. They were dissimilar in surface areas of the teres major, pronator teres, and supinator.

Although both males and females at Tipu demonstrate homogeneity in the development of some entheses, they do not demonstrate complete homogeneity in all upper limb entheses development. Therefore, hypothesis 2 is not supported.

Hypothesis 3: The Tipu burial sample will more closely resemble non-elites in upper limb musculature.

Comparisons of entheses development among all burial samples (Tipu burials, elites and non-elites) produced a complex set of results that ultimately do not support

hypothesis 3. Elite and non-elite females were not significantly different from females at Tipu (in burial clusters both inside and outside the church structure) in surface areas of the deltoid, pectoralis major, biceps brachii, pronator teres and supinator ($p=0.292-0.329$). The only significant differences among pre-contact and Colonial Period burial samples were for the teres major and brachialis entheses. Elite females had significantly lower mean teres major surface area than all other Tipu females ($p=0.026$) (inside and outside burial samples combined), and both elite and non-elite females had significantly higher mean brachialis surface areas than Tipu females ($p=0.035$ and $p=0.044$ respectively). However, when comparisons were made between elites and non-elites and each Tipu burial group separately, there were no significant differences in these entheses. In other words, when the entire sample of Tipu females was compared to elites and non-elites significant differences in development of the teres major and brachialis were detected. When females from inside and outside burial clusters were compared to elites and non-elites separately, there were no significant differences in enthesis development.

Overall, PCA and Cluster analyses demonstrate females buried both inside and outside the church at Tipu are actually most similar to elite females in development of the majority of entheses analyzed. Non-elite females are generally the most dissimilar to Tipu females. However, within each cluster of Tipu females and elite females, inside and outside burial groups vary in similarity to the elite burial group (Appendix 2). For deltoid surface areas, Tipu females inside the church are more similar to elites than females outside the church are. The opposite is true of surface areas for the teres major, biceps brachii, pronator teres, and brachialis. For these entheses, Tipu females buried outside the church are more similar to elites than females inside. Surface areas for the pectoralis major and supinator entheses create very different clustering patterns. For the pectoralis major, non-elite females cluster with females buried inside the church at Tipu, and elite females cluster with females in the outside burial group. The supinator enthesis demonstrates the opposite; non-elite females cluster with females outside the church, and elite females cluster with the inside burial group at Tipu.

Males buried at Tipu also demonstrate a wide variety of results in upper limb enthesis development when compared with pre-contact elite and non-elite males. The

only significant difference detected by t-tests in all possible comparisons of each Tipu burial group, elites and non-elites was for development of the teres major enthesis. Elite males had significantly lower mean surface area for the teres major than Tipu males buried inside the church walls ($p=0.032$). The development of all other entheses was homogenous among males from all burial groups (elites, non-elites and Tipu).

However, PCA and Cluster analyses produced more complex results. Deltoid surface areas created clusters of pre-contact and Colonial Period burial samples. Males from Tipu burial groups inside and outside the church walls were most similar to one another, and elite and non-elite males were most similar. For the teres major, elite and non-elite males clustered with males buried inside the church, and elite males were most similar to the inside burial group. Males buried outside the church at Tipu were dissimilar to the other three burial groups in teres major enthesis development. Pectoralis major surface areas created a cluster of elite males and males from both Tipu burial groups, where males outside the church were most similar to elites. Non-elite males were most dissimilar in pectoralis major surface area. Elite males and Tipu burial groups also clustered together for biceps brachii surface areas, however, in this case males inside the church were more similar to elites. Pronator teres and supinator were the only entheses that created similar clustering patterns. For both entheses elites and non-elites are most similar and also cluster with the outside burial group. The inside burial group is dissimilar to all other males. Finally, the brachialis is the only enthesis that supported hypothesis 3. Non-elite males clustered with both Tipu burial groups, and elites were most dissimilar. Furthermore, within the cluster of non-elite and Tipu males, the outside burial group and non-elites were most similar.

In sum, a similar clustering pattern was discerned among female burial groups for all entheses, except for the pectoralis major and supinator, where females from both burial groups at Tipu clustered with elite females and non-elite females were most distinct in enthesis surface areas. Such a pattern does not emerge among male burial groups. Because neither males nor females at Tipu clustered consistently with non-elites, hypothesis 3 is not supported.

Discussion

Elites and Non-elites

In general, the hypothesis that pre-contact Maya elites and non-elites would have different patterns of enthesis development reflective of different activity patterns involving the upper limb is supported for females, but not for males. Female elites and non-elites differed in development of all seven entheses recorded. This suggests that females at opposite ends of the Maya social hierarchy differed in habitual activities requiring abduction, extension, and medial rotation at the shoulder joint, and activities requiring elbow flexion with the forearm supinated, supination of the forearm, and pronation of the forearm. These patterns are likely reflective of the agricultural activities that non-elite females engaged in. The deltoid, teres major, biceps brachii and brachialis are muscles frequently used when planting crops, using a mano and metate for grinding corn, and carrying heavy burdens in front of the body (Chapman, 1997). It should be noted, however, that there is no clear pattern of one pre-contact group having more pronounced or more gracile enthesis development. In other words, these data do not support the assumption that non-elites would have consistently more-developed entheses due to more frequent engagement in manual labor.

While male elites and non-elites differed in the development of some entheses, they were similar in the development of others. Elite and non-elite males were similar in development of entheses for the deltoid, teres major, pronator and supinator. They differed in development of the brachialis, pectoralis major and biceps brachii. This suggests that pre-contact male elites and non-elites did similar activities requiring shoulder abduction and extension, and forearm supination and pronation. They differed in activities requiring adduction and medial rotation at the shoulder and flexion at the elbow while the forearm is supinated. It is speculated that the similarities elite and non-elite males show in habitual activity involving the upper limb could be due to similar activity levels. The additional agricultural activities that non-elite males engaged in may account for the differences between the two social groups. Differences in development of the

brachialis, pectoralis major and biceps brachii are also consistent with muscle actions required for preparing soil, planting crops and carrying heavy burdens in front of the body (Chapman, 1997). Among the Maya, clearing land for milpas using flint blades and axes in a chopping motion (Sharer, 1996) would have also required engagement of these muscles. Like female elites and non-elites, males from different social tiers also vary in which group has greater mean surface area for the entheses identified as dissimilar.

Tipu Burial Groups

The hypothesis that burial groups inside and outside the church walls at Tipu will be homogenous in entheses development was not completely supported for males or females. The entheses for which females from inside and outside burial groups were dissimilar were the pectoralis major and the supinator. The evidence indicates that the majority of Tipu females engaged in similar habitual activities involving the upper limb, except for activities requiring medial rotation at the shoulder and supination of the forearm with no flexion of the elbow. There was also a group of females in the burial cluster north of the church structure that demonstrated significantly greater development of the pronator teres.

Males buried inside and outside the church walls were similar in development of the deltoid, pectoralis major, biceps brachii and brachialis. They were dissimilar in development of the teres major, pronator and supinator. Tipu males performed similar activities requiring shoulder abduction, adduction, medial rotation and flexion, as well as elbow flexion and supination while the elbow is flexed. However, they varied in activities requiring extension of the shoulder, and pronation and supination of the forearm. This "variety" of patterns observed for males and females at Tipu required referencing comparisons made with pre-contact Maya samples for clarification. Therefore, the results presented in this section are discussed in more detail below in relation to comparative samples.

The "Status" of Tipu Burial Groups

The overarching prediction of this study that the Tipu burial sample represents a homogenous group of people with lifestyles most similar to those of a pre-contact, non-elite farming community is not supported by the data presented here. There is no clear distinction in patterns of upper limb entheses development among Tipu burial groups that resembles that seen for pre-contact Maya samples. Furthermore, non-elite females are distinct from Tipu females of both inside and outside burial groups in development of the majority of entheses analyzed here. The general picture that emerges is a complex one, in which the activity patterns of Tipu males and females were more diverse than expected. It appears that within each general burial group (inside and outside the church walls) there is more variation in the development of upper limb entheses than predicted, especially for males. It is suggested that this could reflect a degree of task specialization at Tipu, but it could also reflect a more diverse population created by inclusion of immigrants from other Lowland regions (namely northern Yucatan) in the Tipu burial sample (Farriss, 1984; Jones, 1998).

Tipu females from inside and outside burial contexts did not vary as much as elite and non-elite females in upper limb entheses development, which suggests the social structure that existed at the Tipu mission did not involve radically different lifestyles among women. Of the two pre-contact samples of females, Tipu females clustered most often with elite females. Results also suggest the activity patterns of non-elite females were the most *unique* of all the samples of Maya females analyzed here. The term unique is used because there is no clear cut pattern of one burial group having greater or lesser mean entheses surface areas. It would be predicted that pre-contact non-elite females engaged in more manual labor than elite females, and therefore all the entheses of non-elites would have greater mean surface areas. However, this was not the case. Even among the distinct elite and non-elite females, the two groups vary in which entheses have the higher mean. Tipu females inside and outside the church also vary in which entheses are more pronounced. The greater similarity of Tipu females to elites does not necessarily suggest that all females at Tipu were high status, but they were definitely

engaged in activities that differed from those of pre-contact non-elites whose activities are assumed to be centered on the needs of an agricultural community. Perhaps these results are indicative of a higher degree of task specialization among females of the Tipu mission.

This idea of task specialization is further supported by the significantly greater development of the pronator teres among females buried in the *atrio*. The pronator teres is only active in pronation of the forearm. It is therefore speculated that these females represent a group of women who specialized in some type of handicraft. This specialization is also supported by the finding (presented in Chapter 4) that the same females were significantly more gracile in cross-sectional properties of the humerus, femur and tibia. One of the main domestic industries of the Maya, performed primarily by women, was weaving cotton into cloth (Farriss, 1984). Cotton mantas were also produced for tribute payments (Clendinnen, 2003). The combination of skeletal gracility and greater development of the pronator teres could suggest that some women did not do as much labor involved in subsistence tasks and spent more of their time doing tasks like weaving and/or sewing. These patterns of bone functional adaptations observed for women buried in the *atrio* could further signify that it was also a high status burial location and that certain task specializations led to higher status.

Tipu males buried inside and outside the church structure differ in the development of some entheses and are similar in others. However, entheses that were, or were not, similar do not conform to the same pattern seen between pre-contact elite and non-elite males. Therefore, like females, entheses development among Tipu males does not mimic that seen between disparate social tiers in pre-contact times. Elite and non-elite males were also more similar to one another for more entheses than either Tipu burial group was to pre-contact groups. At the same time, pre-contact elite and non-elite males were not so drastically different in upper limb musculature to begin with, and may have had similar activity levels. It seems that this same overlap in activity patterns also occurred among males of different burial locations at Tipu. Because Tipu males did not demonstrate the same differences in entheses development as pre-contact elites and non-

elites, it is speculated that there may have also been a greater degree of task specialization among males in the Colonial Period.

Support for this speculation is provided by differential development of both the pectoralis major and supinator among males buried inside the church walls. Tipu males buried inside the church near the altar exhibited less development of both the pectoralis major and supinator entheses. Differences between these males and other males at Tipu was not quite significant, but marginal p-values for tests with low statistical power are worth describing.

Male elites and non-elites were also significantly different in development of the pectoralis major, which may reflect the agricultural activities of non-elites. For instance, the shoulder flexion, adduction, and medial rotation that the pectoralis is involved in, are all actions required for chopping (i.e. with an axe or machete). Because Maya men devote a majority of their time to agricultural activities, and one of the most strenuous activities involved is using an axe or machete to fell bush for several milpas a year (Redfield and Villa Rojas, 1964), it is likely that differential development of the pectoralis major is associated. This leads to the speculation that the men buried near the altar may have had occupations that did not require them to be full-time farmers like all other males at Tipu. In contemporary Maya communities, men typically rotate through public offices, and are therefore engaged in administrative and community planning activities for only a week or so at time (Redfield and Villa Rojas, 1964). Although *maestros cantores* (men in charge of leading Catholic services and rituals) have specialized occupations, they are still active parts of the pool of communal labor and are responsible for doing their own farming (Farris, 1984; Redfield and Villa Rojas, 1964; Tozzer, 1941). If this type of social organization was in effect at Tipu, it would be expected that even males buried near the altar would demonstrate the same upper limb use as all other males. However, differential development of the pectoralis suggests there may have been men who devoted more of their time to positions like *maestro cantor* or a public office. This is further supported by less developed supinator entheses observed among men buried inside the church in the center burial cluster and near the altar. Like the pectoralis major, the supinator would also

be active for tasks like using axes or machetes to clear bush, as well as for either pulling or cutting weeds in milpas (among other activities).

Another possible explanation for unexpectedly diverse patterns of entheses development, especially among males, is that Tipu was not a closed, completely isolated population. Maya from colonies in northern Yucatan frequently fled the harsh conditions there for refuge in the frontier zone and settled at Tipu (Farriss, 1984; Jones, 1998). Additionally, when the Itzá Maya took up colonization efforts of their own to keep Spaniards out of the Petén region, they relocated people from smaller surrounding communities to Tipu (Graham, 2011; Jones, 1998). Both of these events meant that Maya from other Lowland regions were likely added to the burial sample at Tipu. A greater diversity of activity patterns involving the upper limb could reflect interregional differences in subsistence strategies.

Other factors to consider are that we do not know how the Maya at Tipu may or may not have accommodated the social status of immigrants, or whether they perceived there to be enough room left in the nave for additional burials after a certain amount of time. The burial sample there accumulated over a span of roughly 100 years, so it is possible that temporal changes occurred in where Tipuans interred people, and that later in Tipu's burial sequence social status had less to do with where individuals were placed in relation to the church. To address this issue, a better understanding of the burial sequence at Tipu is needed, along with isotopic data could delineate individuals from different regions.

Conclusions

This study did not detect differences among Tipu burial groups that indicate pre-contact social tiers persisted in the context of the *visita* mission. Patterns of entheses development, among both males and females, indicate that there was a different type of social organization at Tipu where the lifestyles of high and low status people were not as clear cut. In general, a more diverse pattern of upper limb use than expected was observed for both males and females, which may suggest a higher level of task

specialization among Tipuans. There is some evidence that males buried inside the church and near the altar, and females buried in the *atrio*, engaged in more specialized tasks. However, a better idea of the burial sequence at Tipu and the diversity of regions that immigrants came from is needed to further investigate this speculation.

Chapter 4.

Colonial Period Social Structure and Activity Patterns at Tipu from the Perspective of Cross-sectional Bone Morphology

Introduction

Spanish colonization in the Americas took a variety of forms and led to a variety of cultural outcomes for indigenous populations (Farriss, 1984; Gasco, 2005; Graham, 2011; Larsen et al., 2001). Even within the Maya Lowlands, a region encompassing what is now Yucatan, Campeche, Quintana Roo, Belize and part of Guatemala, the signatures of Spanish colonization were diverse. Many coastal villages in northern Yucatan were heavily occupied due to the economic exploits of Spaniards, and changes to indigenous lifeways were drastic. In contrast, the *visita* missions of central Belize were only visited occasionally by Spanish friars attempting to ensure indigenous adherence to Christianity. Churches were constructed within communities of this region, but traditional lifeways continued (Graham, 2011; Jones, 1989; 1998). Here the Colonial Period (AD 1544-1707) burial sample from Tipu is used as a case study for exploring the effects of colonization and Christianization on the social structure of a Maya community at the periphery of Spanish colonization efforts. Social structure is examined through the evidence provided by skeletal signatures of activity patterns, under the assumption that individuals of different social status engaged in different habitual behaviors.

Activity patterns of the Tipu burial sample are examined using cross-sectional properties of the humerus, femur and tibia. The same data was collected from samples of pre-contact Maya elites and non-elites to serve as a basis of comparison for evaluating the variation in cross-sectional morphology of the upper and lower limb at Tipu. The ultimate goal is to determine whether activity patterns involving mobility and upper limb use varied by burial placement at Tipu, and therefore by status within the Spanish-imposed social system. This paper summarizes the historical and archaeological background of

Tipu that inspired the research questions and hypotheses listed below. It also summarizes the applications of cross-sectional geometry (CSG) in contemporary and past populations. A new method for measuring CSG from three-dimensional (3D) images of long bones (Davies et al., 2012) is detailed along with the results these data produced.

Research Questions and Hypotheses

This study addresses three main questions:

- 1) Are there differences in the cross-sectional morphology of upper and lower limb long bones between pre-contact elites and non-elites?
- 2) Are there significant differences among burial groups at Tipu, and therefore some evidence of a social structure where activity patterns varied among status groups?
- 3) How do the long bone cross-sectional properties of people interred at Tipu compare to pre-contact Maya at opposite ends of the Classic/Postclassic social hierarchy?

Answering the first research question establishes how different the samples of pre-contact Maya from disparate social tiers actually were in mobility patterns and upper limb use and therefore influences how question three will be answered. The second and third questions are aimed at determining whether there is evidence from CSG of the upper and lower limb that there were distinct social tiers at Tipu.

It should be noted that this study employs a simplified, working model and that a variety of factors, discussed in more detail below, could have contributed to the distribution of burials at Tipu. It is also understood that a dichotomous view of the Maya as either elite or non-elite, high or low status, is not necessarily representative of their pre- or post-contact society (Chase, 1992). However, the nature of both pre-contact comparative samples and the Tipu burial sample, and the nature of skeletal indicators of activity, do not allow examination of gradations in social status in this study. Pre-contact comparative samples were deliberately chosen to represent individuals at opposite ends of the Maya social pyramid, in order to determine whether their lifestyles were drastically different, as we often assume. These samples were also chosen with the idea that they

would create the most contrast between pre- and post-contact social organization if there was in fact a reorganization of society within the Christianized Maya community at Tipu. Throughout this study pre-contact comparative samples are referred to as elite or non-elite, with the understanding that this is a simplified representation of Maya society. Elite refers to individuals who would have had more prestige, power and wealth than the rest of pre-contact Maya society (Chase and Chase, 1992; Sanders, 1992). Non-elite refers to individuals from rural, agricultural communities that were subsidiary to major Classic/Postclassic centers of political/economic power. Individuals at Tipu are referred to as high or low status based on their burial location inside or outside the church walls, respectively, again with the understanding that this is likely a simplified representation of their social status. Reference to Tipuans as either high or low status, rather than elite or non-elite, is meant to signify that it is not assumed that these pre-contact social tiers persisted in the Colonial Period.

To address each of the three questions listed above, the three associated hypotheses below are tested.

H1) Since the lifestyles of Maya from different social strata varied (Adams, 1970; Chase and Chase, 1992; Inomata and Triadan, 2000) and decrease in skeletal robusticity has been shown to coincide with increase in a Maya community's administrative function (Maggiano et al., 2008), it is predicted that *there will be differences between elites and non-elites in cross-sectional morphology.*

H2) Because previous studies demonstrated homogeneity in skeletal robusticity among Tipu burial groups with linear dimensions of long bones (Cohen et al., 1989, Wrobel, 2003), it is hypothesized that *CSG properties of the humerus, femur and tibia will be homogenous among males and females at Tipu.*

H3) The previously observed homogeneity in skeletal robusticity at Tipu, coupled with the fact that a few individuals buried inside the church were actually more robust than individuals buried outside (Armstrong, 1989; Cohen et al., 1989; Wrobel, 2003) leads to the prediction that *the Tipu Maya will be more similar to non-elites in CSG.*

Historical and Archaeological Background

Spanish colonization in Mesoamerica began with the arrival of Hernan Cortes in 1519. The Aztec Empire, which dominated the region from central Mexico and Guatemala to Honduras, was overthrown within a couple years of their arrival (Charlton and Fournier Garcia, 1993; Jones, 1989; Palka, 2009). However, it was not until 1527 that colonization and Catholic missionization of the Yucatan and Maya Lowlands began (Jones, 1989). Longer still was the process of colonization and subjugation of indigenous groups in what is now Belize and the Petén region to the west (Jones, 1989; 1998), due to several cultural and environmental factors (Graham, 2011). The central and southern Lowlands (i.e. Belize) were not high priorities for commercial exploitation because the region lacked resources that were of great value to the Spanish (i.e. gold and other precious metals) (Farriss, 1984; Graham, 2011; Jones, 1989; 1998). Maya political systems were also more fragmented, rather than highly centralized (as the Aztecs were), so they were more difficult to bring under control all at once (Cecil, 2009b; Farriss, 1984; Jones, 1989; 1998). This problem was further confounded by the dispersed nature of Maya communities and their inaccessibility to Spaniards unaccustomed to the terrain and climate of inland locales of the frontier zone (Farriss, 1984; Graham, 2011; Jones, 1989; 1998). Efforts at *reduccion*, which was the forced consolidation of indigenous communities into one large, more easily controlled village, proved very difficult for the above reasons and such inland colonies were rarely maintained if Spaniards left (Jones, 1998). In sum, the process of conquest for Tipu and surrounding Maya communities was not as severe as it had been for populations of central Mexico (Farriss, 1984; Jones, 1989; 1998; Jones and Pendergast, 1991). In fact, Tipu was a refuge for people fleeing the more heavily controlled colonies of northern Yucatan where *repartimiento* (forced labor systems) negatively affected Maya lifeways (Farriss, 1984; Graham, 2011; Jones, 1998).

Tipu was a community in the Macal River Valley in west central Belize with archaeological evidence of continuous occupation from the Late Preclassic (~300 BC) through the Spanish Colonial Period (AD 1544-1707) (Graham, 1991; Jacobi, 2000). Franciscan missionaries were the primary colonizers of the region. Despite being greatly

outnumbered by indigenous people, they established *visita* missions that endured (Graham, 2011). The mission at Tipu is documented both historically and archaeologically (Cohen et al., 1989; 1994a; 1994b; Graham, 1991; 2011; Graham et al., 1985; 1989; Jones, 1989; 1998; Scholes and Thompson, 1977). Despite inconsistent Spanish presence there, both lines of evidence suggest complete acceptance and persistence of Christianity from 1544 until the Maya there were forcibly removed in 1707 (Graham, 2011). Tribute was paid to the Spanish administration in goods that the Maya at Tipu had been producing centuries before contact (Graham, 2011). There are no documented demands for increased production (Danforth et al., 1997), and subsistence strategies were continuous throughout the Colonial Period (Emery, 1999). Therefore, it seems there were no drastic changes in indigenous lifestyles that coincided with conversion to Christianity (Graham, 2011). Archaeological evidence indicates that use of Postclassic ritual structures continued into the Colonial Period (Graham et al., 1985), and Spanish goods were found in association with Postclassic architectural features (Cohen et al., 1994a). In addition to continued use of Postclassic structures and ritual spaces, trade goods and ceramics suggest Tipu remained part of the un-colonized Itzá Maya economic sphere (Cohen et al., 1994a; Jones, 1982).

Several lines of archaeological evidence exist for continuity in subsistence strategies at Tipu. There were no changes in slips, paints or general vessel appearance of locally produced pottery, and no changes in lithic technology (Graham, 2011). Despite introduction of some metal tools by Spaniards, the new implements never dominate assemblages (Graham, 1991). Faunal assemblages indicate a continuous, highly generalized use of a variety of animal species from all available ecosystems from the Postclassic through the Colonial Period (Emery, 1999), and continued trade for marine resources with coastal communities (Graham, 1991). Milpa farming was continually used to grow corn, squash, beans, chiles, sugar cane, and plantains, and production of cacao persisted because it remained a valuable commodity (Jones, 1982). In the Classic Period, cacao was the economic base of Tipu elites; the Spanish accepted it as tribute in the Colonial Period (Jones, 1982; Graham et al., 1985). Documents written by Spanish friars indicate corn milpas were harvested two or three times per year, which suggests intensive

cultivation during the Colonial Period (Jones, 1982). However, this intensity of cultivation is also documented among contemporary populations and was likely normal practice in pre-contact times to offset the danger of crop failure due to floods or unpredictable rainfall (Jones, 1982; Redfield and Villa Rojas, 1964).

Of interest here is whether continuity also existed in the social structure of the Christianized Maya community. European Catholic custom dictated that individuals of higher status be buried inside church structures, those of highest status be buried near the altar, and those of lower status be buried outside the church walls in cemeteries (Jacobi, 2000; Jones, 1989; Miller and Farriss, 1979; Muller-Wille, 1993). Interment of individuals in various places under the church floor, near the altar, and outside the church structure suggests there was some type of hierarchy in place at Tipu reflecting European custom. The historical record documents the presence of a ruling class at Tipu and names associated with elite lineages of the un-colonized Itzá Maya of the Petén region to the west (Jones, 1998; Scholes and Thompson, 1977). However, there is no archaeological or human skeletal evidence, besides burial placement, indicative of differential social status among Maya individuals buried in and around the church structure (Cohen et al., 1994b; Danforth et al., 1997; Jacobi, 2000; Wrobel, 2003).

If all segments of pre-contact Maya society were intact and all were indoctrinated into the Colonial Period Christian community, there should be at least some skeletal evidence of differential status within the church burial sample. Thus far none have been distinguished (Cohen et al., 1989; Cohen et al., 1994b; Jacobi, 2000; Wrobel, 2003). Skeletal signatures of nutritional deficiencies or illness (e.g. porotic hyperostosis) and stature do not vary significantly between individuals buried inside and outside the church walls (Cohen et al., 1989; Cohen et al., 1994b; Jacobi, 2000). Long bone robusticity is also relatively homogenous among the burial clusters at Tipu (Armstrong, 1989; Cohen et al., 1989; Wrobel, 2003). This suggests that individuals buried inside the church, and of presumably higher status, did not have significantly different lifestyles than all other individuals buried within the context of the Christian church. In other words, because it has been shown that pre-contact Maya elites can be distinguished from non-elites based on skeletal indicators of health and differential access to resources (Cucina and Tiesler,

2003; 2007; Somerville et al., 2013; White et al., 1993), the leaders of the newly established Christian community at Tipu likely had lifestyles different from the pre-contact elites . It is this suggestion that led to the third hypothesis listed above.

At the same time, it is understood that skeletal indicators of "health" and diet do not always conform to such a pattern among individuals of different social status (Powell, 1992; Robb et al., 2001; Silverman, 2002). This study represents another line evidence for exploring the social hierarchy that existed at Tipu after missionization. Does the Tipu burial sample represent a community where the pre-contact hierarchy simply transferred to the newly established Christian community, or does it represent a community where the adoption of Christianity created a new social structure where commoners gained the opportunity to take on leadership roles?

Cross-sectional Geometry and Activity Patterns

The question above is explored using the cross-sectional shape and robusticity of upper and lower limb long bones. The observable adaptation of long bone morphology to an individual's activity patterns is known as bone functional adaptation (Lanyon, 1982; Lanyon and Skerry, 2001; Pearson and Lieberman, 2004; Ruff et al., 2006). An extensive body of work demonstrates that activity induced stresses on the skeleton lead to deposition of bone to accommodate biomechanical forces, and inactivity leads to bone resorption (eg. Demes, 2007; Goodship et al., 1979; Lanyon and Rubin, 1984; Lee et al., 2002; Martin et al., 1998; Woo et al., 1981). The effects of activity-induced biomechanical forces on human skeletal elements are commonly quantified by applying the engineering principle of beam theory to the cross-sectional geometric (CSG) properties of a long bone diaphysis (Larsen, 2002; Ruff, 2008).

The cross-sectional properties of a long bone, modeled here by a beam, are used to calculate the stresses it experiences in response to externally applied loads (Ruff, 2008). The primary types of stress long bones endure are bending and torsion. Bending and torsional rigidity (the resistance of a structure to deformation before fracture) are proportional to cross-sectional properties called second moments of area (SMAs). SMAs

are the product of small unit areas of material multiplied by the squared distances of the areas to an axis (Ruff, 2008). They are essentially a measure of the distribution and distance of material from an axis that models the direction of applied force; the greater the amount of bone and its distance from the center of a cross-section, the greater its strength in resistance to bending and torsional forces. In the skeletal application of beam theory, SMAs are calculated about the anatomical axes of a long bone: antero-posterior (AP) and medio-lateral (ML), where AP and ML axes represent maximum and minimum SMAs and are proportional to maximum (*I_{max}*) and minimum (*I_{min}*) bending rigidity of a cross-section (Ruff, 2008). While these axes are not necessarily in the same plane of actual bending forces on a long bone (due to the organic shapes of skeletal elements), they correlate well with cross-sectional properties calculated about centroidal axes (Lieberman et al., 2004). To calculate torsional rigidity, SMA is calculated about an axis through the centroid of cross-section, and in this case is called the polar second moment of area (*J*). *J* is proportional to torsional rigidity, as well as the average bending rigidity of any two perpendicular planes, making it an indicator of the overall strength of a long bone (Ruff, 2008). In addition to these measures of bending and torsional rigidity, the relative distribution of bone in a cross-section is measured with total subperiosteal area (*TA*), or the area encompassed by the outer perimeter of a cross-section, which is another measure of overall bone robusticity (Ruff, 2008; Shaw and Stock, 2009).

These measures (and others) of long bone CSG, which allow quantification of bone functional adaptations, have been utilized extensively by anthropologists to investigate a variety of research questions related to human variation and the biomechanics of the human skeleton. Research topics include: evolutionary trends in long bone morphology from early *Homo* to modern humans and their corresponding behavioral changes; the effects of subsistence strategies, mobility patterns and terrain on long bone morphology; and the effects of activity level and age on the skeleton (Larsen, 2002; Ruff, 2008). While it is important to consider that the shape of a given bone is also influenced by biological factors like genes and hormones, and degrees of bone remodeling vary throughout the life course (Gosman et al., 2011; Pearson and Lieberman, 2004), the use of CSG to make inferences about bone functional adaptation is further

supported by *in vivo* studies of athletes (eg. Haapasalo et al., 2000; Jones et al., 1977; Kannus et al., 1995; Kontulainen et al., 2003; Shaw and Stock, 2009). For instance, structural properties of the humerus and tibia are heavily influenced by activity patterns begun during adolescence and the types of activities performed (Kannus et al., 1995; Kontulainen et al., 2003; Shaw and Stock, 2009). Kannus and colleagues (1995) showed bone mineral density was significantly greater in the upper limb long bones of female tennis and squash players versus non-athletic females, and that due to the unilateral arm use required by these sports, upper limb bone mineral density of the female athletes was more asymmetrical. Kontulainen and colleagues (2003) also showed that the cross-sectional shapes and asymmetry of the upper limb long bones of racquetball players were distinct from those of non-athletes. Shaw and Stock (2009) demonstrated that the cross-sectional properties and shape of the tibia varied markedly among college athletes who engaged in distance running versus field hockey, starting around age ten, due to the very different directional forces applied to the tibia by extensive participation in each sport.

Bioarchaeologists seeking to reconstruct the activity patterns of past populations have used the CSG of upper and lower limb long bones to make inferences about subsistence strategies, change in subsistence strategies over time, and sexual divisions of labor (Carlson et al., 2007; Fresia et al., 1990; Larsen et al., 1995; Larsen, 2002; Ledger et al., 2000; Maggiano et al., 2008; Marchi et al., 2006; Ogilvie and Hilton, 2011; Ruff, 2000; Sladek et al., 2006; Sparacello and Marchi, 2008; Sparacello et al., 2010; Stock and Pfeiffer, 2001; Weiss, 2003b; 2005; 2009; Wescott, 2006). For instance, in a comparison of terrestrial and marine foragers, Stock and Pfeiffer (2001) showed that terrestrial foragers had more robust femora and tibiae than marine foragers due to their more frequent travel on foot over uneven terrain. Conversely, marine foragers had more robust clavicles and humeri because they primarily traveled by rowing boats, and therefore had more consistent and heavier biomechanical loading of the shoulder girdle (Stock and Pfeiffer, 2001). Other studies have documented significant cross-sectional morphology changes in past populations that transitioned from hunting and gathering to agriculture (Bridges, 1989; Brock and Ruff, 1988; Larsen, 1982; Ruff et al., 1984; Ruff, 1987; Ruff and Larsen, 1990). In general, changes in CSG included reduction in femoral robusticity

due to more sedentary behavior (Cohen and Armelagos, 1984; Larsen et al., 1996; 2001; Ruff et al., 1984), less sexual dimorphism in femoral shape for the same reason (Ruff, 1987), and increased humeral robusticity among females that is symmetrical due to more bilateral use of the upper limbs for tasks such as grinding grain (Bridges, 1989; Fresia et al., 1990).

CSG has also been applied to investigating the effects of Spanish colonization on the activity patterns of indigenous populations. Documented changes in CSG of the upper and lower limb from pre-contact to contact periods among the Guale tribe of the southeastern United States (in what is now Georgia and northern Florida) were mainly due to the increased labor demands imposed by Spanish conquistadors (Larsen and Ruff, 1994; Larsen et al., 1996; 2001; Ruff and Larsen, 1990). At the Mission Santa Catalina de Guale on Saint Catherine's Island, contact period Guale males demonstrated increased variation in femoral robusticity from pre-contact agricultural to contact period samples, indicating that some males experienced increased mobility in the contact period, while other males and Guale females did not (Ruff and Larsen, 1990). This can be explained by historical documentation of the *repartimiento* system enforced at Santa Catalina, which was a labor draft imposed by Spaniards that required some men to make periodic trips to the colony at Saint Augustine and elsewhere (Ruff and Larsen, 1990). While the upper limb CSG of Guale males did not change from pre-contact to contact periods, the robusticity of female humeri actually decreased in the contact period (Ruff and Larsen, 1990). Ruff and Larsen (1990) attribute this to a decrease in general activity levels among females in relation to males, and the general increase in the demands placed on males. In addition, regardless of sex, femoral midshaft CSG generally trended toward being more circular in the contact period, and the mid-distal humerus (immediately distal to the deltoid tuberosity) trended away from circularity (Larsen et al., 1996). More circular femora are indicative of increased sedentism in the colonial period (Larsen et al., 1996; Ruff and Larsen, 2001), and less circular humeri suggest an increase in biomechanical loading of the upper limb from lifting and carrying heavy loads. More specifically, this ML expansion of the mid-distal humerus was likely due to increased loading of

brachioradialis and extensor muscles, which are involved in elbow flexion and extension (Drake et al., 2005; Ruff and Larsen, 2001).

It is important to note that although Spanish colonization efforts were far reaching in Mesoamerica and southern North America, their effects on indigenous populations were not uniform (Farriss, 1984; Gasco, 2005; Graham, 2011). Therefore, it is stressed that Tipu is a unique outcome of Spanish colonization, and the same trends in CSG described above are not expected. A predominant goal of historical archaeologists studying the varied results of European colonialism in the Americas has been to gain a better understanding of the colonization process as it has occurred cross-culturally throughout human history (Gasco, 2005). One general principle that emerges from archaeological and historical studies of colonialism is that the nature of the interplay between two societies brought into contact by colonization efforts, and the societal end results, depended on many different factors specific to a given location and time period (Farriss, 1984; Gasco, 2005; Graham, 2011; Rogers, 2005). Consideration of all contextual factors is particularly important for this study in its attempt to make inferences about changes to Maya social hierarchy from the Tipu skeletal sample because colonization efforts at Tipu were distinct from those elsewhere in New Spain.

Materials

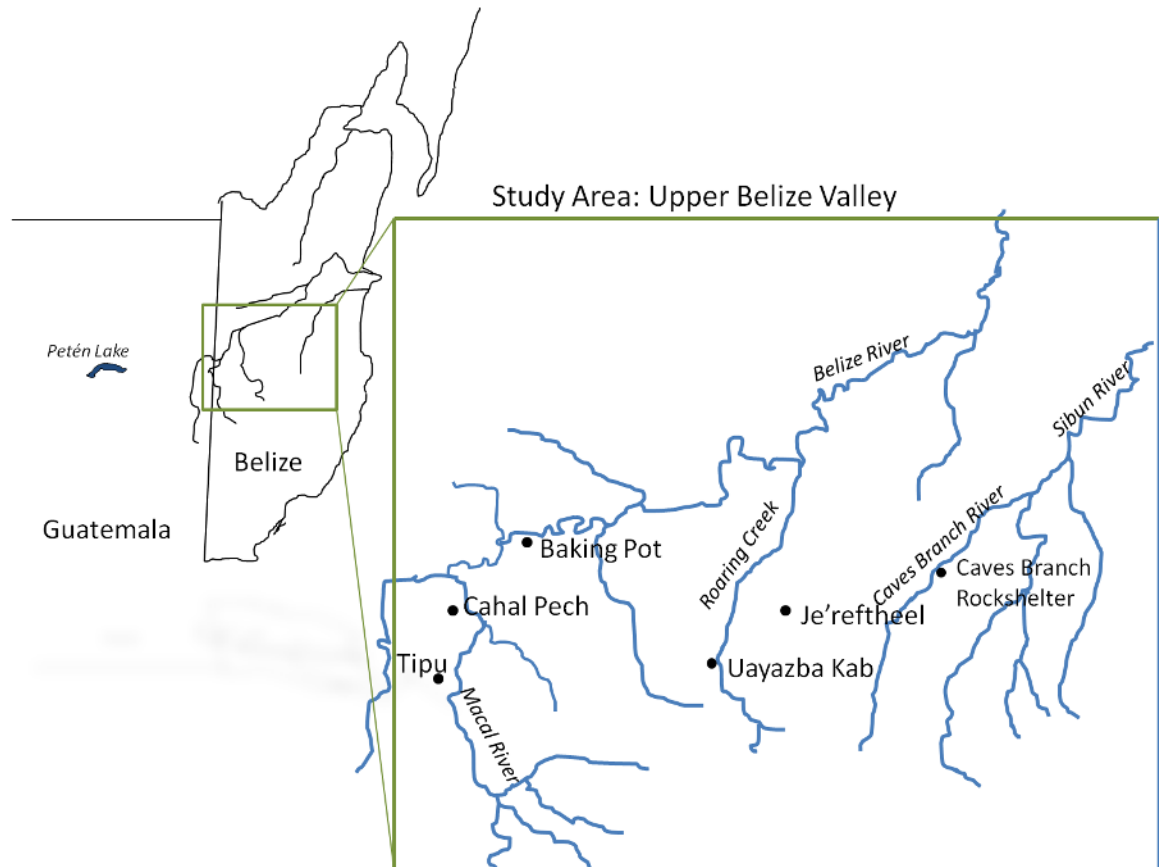
To be included in this study, an individual's long bones had to have good cortical preservation and a relatively complete diaphysis. Since skeletal markers of biomechanical stress are assumed to be aggregates of lifetime activity, and bone reaction to mechanical loading varies between periods of growth and after cessation of growth (Bass et al., 2002; Gosman et al., 2011; Kannus et al., 1995; Pearson and Lieberman, 2004), juveniles (under age 18 at death) were excluded from this study. Individuals with evidence of severe trauma, such as abnormal ossification of muscle or ligamentous tissue (i.e. bony spicules projecting from muscle insertion sites), misaligned long bone fractures, periostitis or evidence of other pathologies that could have altered long bone shape or an individual's activity patterns were also excluded.

In order to interpret patterns of bone functional adaptations observed within the Tipu skeletal sample, it was first necessary to compare this sample of Colonial Period Maya remains with pre-contact Maya remains representative of elite and non-elite social tiers. All skeletal material analyzed comes from previously excavated and curated collections from central Belize. The elite comparative sample is comprised of individuals associated with monumental architecture at Cahal Pech and Baking Pot and elites from a cave context at Je'reftheel. The non-elite comparative sample includes individuals interred at Caves Branch Rockshelter and Actun Uayazba Kab (Table 4.1) (detailed site descriptions of all sites listed are included below). Tipu, Baking Pot, and Cahal Pech are located in the Upper Belize Valley (Figure 4.1). Je'reftheel and Actun Uayazba Kab are located in the valley of Roaring Creek, which is a tributary of the Belize River, and Caves Branch Rockshelter is named for its location in the Caves Branch River Valley, which empties into the Sibun River. All sites sampled are in a similar topographic region of central Belize at the northern edge of the Vaca Plateau and Mountain Pine Ridge to control for variation in skeletal responses to activity caused by interregional cultural and environmental differences. These regional differences among Maya communities of the Lowlands included: variation in terrain, subsistence strategies, and political and economic networks, which ultimately affected the nature of pre-contact and Colonial Period tribute requirements and the daily lives of members of all social tiers. The following is a brief summary of the environmental, cultural, and social factors that were the context for the daily lives of the Maya in central Belize.

Table 4.1: Sample sizes

Site	total <i>n</i>	females	males
Tipu	106	45	60
Non-Elites:			
Caves Branch Rockshelter	58	28	30
Actun Uayazba Kab	2	2	--
Elites:			
Je'reftheel	36	14	22
Cahal Pech	3	--	3
Baking Pot	4	1	3

Figure 4.1: Map of Study Area -- Upper Belize Valley



Most Maya settlements and major centers of the study region were located on or near rivers. Subsistence strategies in the Belize River Valley and surrounding regions from the Classic to Colonial Period involved milpa agriculture for growing maize, beans and squash, growing and harvesting cacao, hunting and gathering plant and animal species in the surrounding jungle, and exploiting river species such as fish and *jute* (snails) (Emery, 1999; Sharer, 1996). Travel along the Belize River and its tributaries on foot and via watercraft was also frequent because the river was a major trade route fed by coastal commerce for centuries before contact (Graham, 2011). The combination of farming and hunting/gathering would have required traversing a variety of terrain, from wide, flat alluvial river valleys to the more rugged terrain to the south. In contrast, coastal Maya communities that drew from marine resources and practiced marshland farming would have primarily dealt with a flatter and much less varied landscape.

Since there was no single, dominant Maya center governing all settlements in the Lowlands (Cecil, 2009a; Jones, 1989; 1998; LeCount, 2001; Masson, 1997; 1999; 2000a), there was also regional variation in the tribute systems that structured the lives of both elites and non-elites. The labor demands and tribute requirements made by centers governing coastal Maya communities, for instance, were different from those made by major inland centers. All elite sites considered in this study were part of the same "power network" which is thought to have been controlled by the most powerful centers in the Petén region of Guatemala (Ashmore and Sabloff, 2002; Audet, 2006; Ball and Taschek, 2004). While the Belize River Valley was characterized by shifts of power among its major centers from the Preclassic to Terminal Classic (Leventhal and Ashmore, 2004), lack of archaeological differentiation among elite sites in the Belize River Valley suggests minimal variation in the nature of the region's hierarchies (Audet, 2006). Maya communities (elite and non-elite) in the Roaring Creek, Caves Branch and Macal River Valleys were also connected to these major centers of the Belize River Valley via political and economic networks (Awe, 1998; Helmke, 2006; Isihara, 2000; Moyes, 2008). In sum, the sites chosen for this study control for the influence of regional political systems on the daily lives of Maya people. The elites represented were part of the same the political hierarchy and the non-elites represented were part of the same political and economic network.

The Tipu Burial Sample

Surveys in the early 1980s led to discovery of the church at Tipu. Excavations that began in 1986 uncovered one church structure, its associated plaza, and a total of 585 historic period burials (176 males, 119 females, 249 juveniles, and 49 adults of unknown sex) (Graham, 2011; Jacobi, 2000). Of these burials 45 females and 60 males were analyzed here for bone functional adaptations because they met the preservation and age requirements detailed above. No individuals under the age of 20, or over the age of 50 were analyzed. The church structure, often termed a *ramada* (or open) chapel, is close to the Macal River, on its west bank, above the modern floodplain. It is 23m long and 8m

wide, with apsidal east and west ends, and 80cm thick walls that were plastered (Graham, 2011). Except for around the altar, where stone walls reached the ceiling, the north, south and west walls were likely about 1.5m high (Graham, 2011). The upper half of the church was made of a wood frame and thatched roof (Jacobi, 2000). The architectural style of the church is typical of mid 16th century church constructions and was likely built in the early 17th century when Tipu was established as an *encomienda* and *visita* mission (Jacobi, 2000; Graham, 2011). In addition to the church, a rectangular plaza and several other Colonial Period structures that incorporated foundations of Late-Postclassic buildings were built on top of debris from Postclassic occupations (Graham, 1991). To the north of the church structure, there was an *atrio* (courtyard) and the foundation of a rectory (residence for visiting friars) (Graham, 2011).

The majority of individuals at Tipu were likely interred in and around the church structure continuously from the establishment of the mission in 1544 to at least 1638, when a major rebellion forced temporary abandonment and possibly the destruction of the church (Graham et al., 1989; Graham, 2011). However, evidence that the northern courtyard was disturbed for later burials, after the church and its associated buildings had collapsed, indicates Tipuans continued using the cemetery throughout the 17th century (Graham, 2011), perhaps until the community was forcibly removed in the early 1700s (Graham, 2011; Jones, 1989). Average age at death for adults (determined from osteological age indicators) was 28.5 years (Danforth et al., 1997), so Tipu represents a relatively "young" burial sample.

European Catholic tradition dictated that individuals of higher status be buried inside the church walls, and those of highest status buried closest to the altar; people of lowest status were buried outside the church walls (Miller and Farriss, 1979; Muller-Wille, 1993). Regardless of status, all individuals were to be buried with their heads to the west and feet to the east (Jacobi, 2000; Jones, 1989; Miller and Farriss, 1979; Muller-Wille, 1993). At Tipu, males, females and juveniles were buried both inside the church walls (in what would have been the floor of the church) and outside the church walls in clusters to the north, west and south of the structure (Figure 4.2). All but a few individuals were buried in the "proper" orientation with their heads toward the west.

Figure 4.3 summarizes the sample sizes of individuals analyzed here from each burial context. Both inside and outside the church walls, some commingling of human remains occurred when previous burials were disturbed to make room for new burials. Disturbance is most pronounced at the back of the church inside the walls, and the burials that were lined up along the altar exhibited the least amount of commingling (Jacobi, 2000).

Figure 4.2: Tipu Site Diagram (arrows indicate the direction of individuals' feet) - created by Justin Sabino

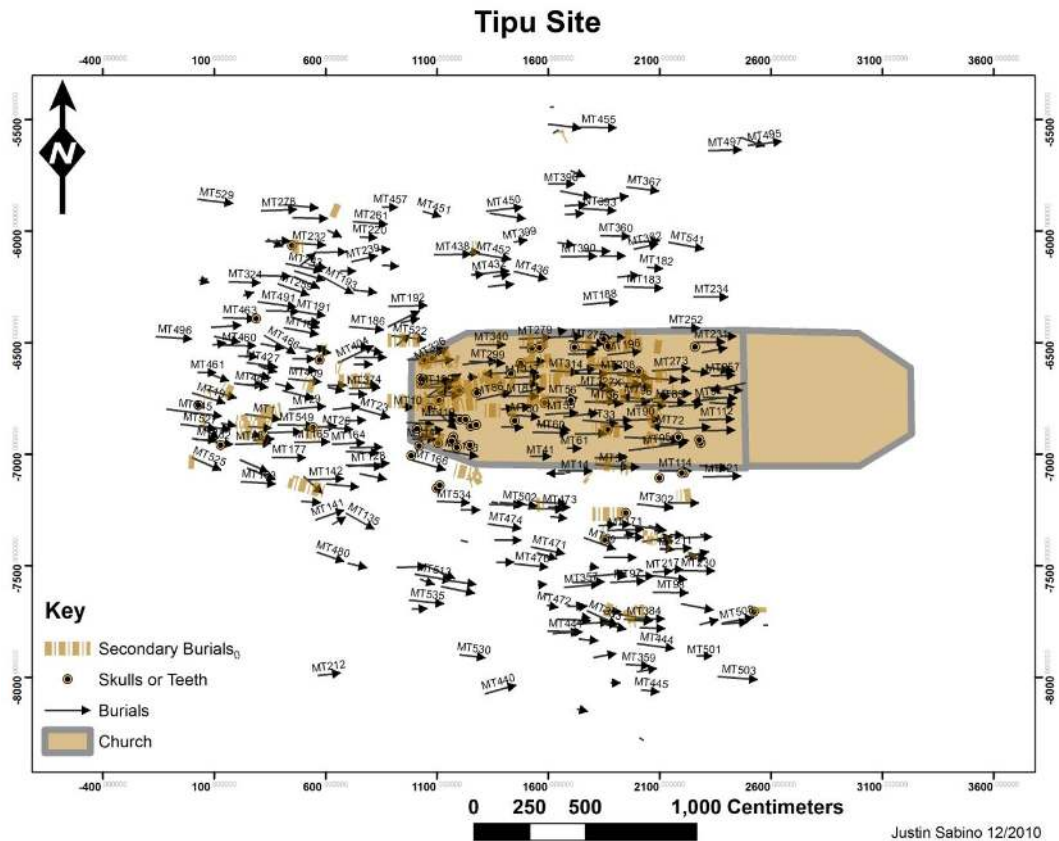
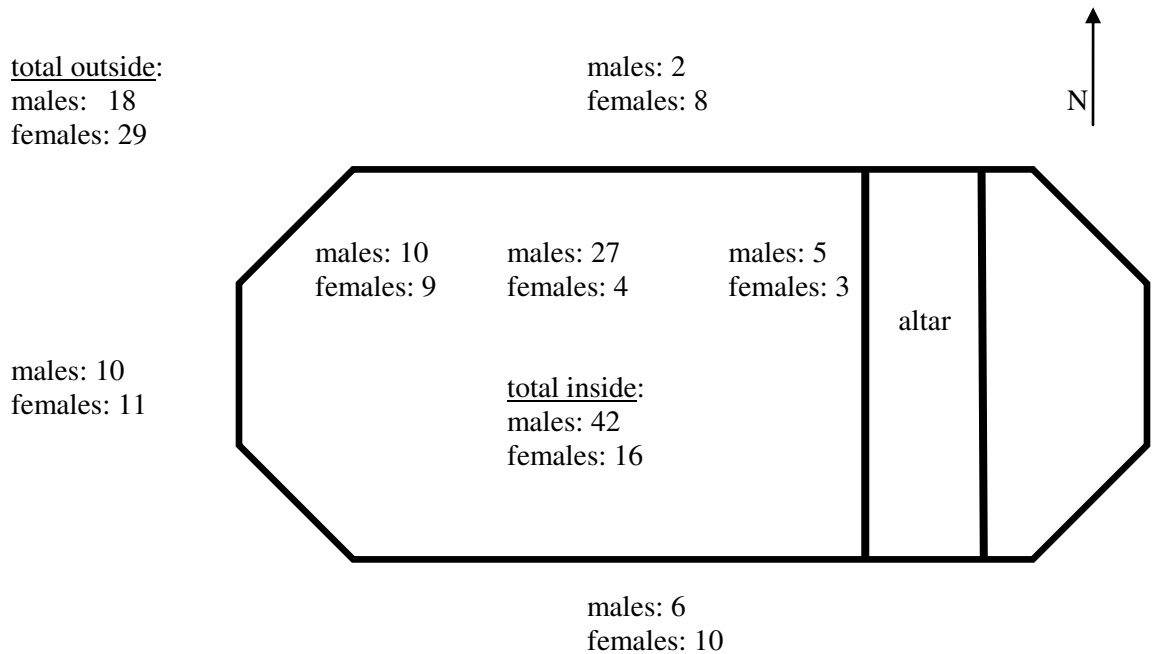


Figure 4.3: Schematic of Tipu church structure and sample sizes from each burial group (not to scale)



Non-metric dental traits, and dental metrics, previously analyzed for all individuals in the Tipu burial sample, are indicative of a relatively homogenous population (Jacobi, 2000). There is no evidence of Spanish admixture, and no Europeans were buried in or around the church. While most individuals were buried in simple shrouds, the few coffin burials that do exist are near the altar and have dental characteristics typical of native Central Americans (Jacobi, 2000).

The skeletal sample at Tipu exhibits low prevalence of chronic infections, nutritional deficiencies, and trauma due to interpersonal violence (Danforth et al., 1997; Jacobi, 2000). Skeletal signatures of nutritional deficiencies or illness (e.g. porotic hyperostosis) and stature do not vary significantly between individuals buried inside and outside the church walls (Cohen et al., 1989; Cohen et al., 1994b; Jacobi, 2000), and general long bone robusticity is relatively homogenous among the burial clusters (Cohen et al., 1989; Wrobel, 2003). Therefore, in addition to lack of differentiation by health indicators, there is little variation in body size among burial groups at Tipu that could indicate differential health or nutrition.

No mass graves are evident, so there is no evidence that epidemics were so severe that many people died all at once (Jacobi, 2000). Colonial documents and census data from 1618 to 1697 do suggest dramatic population fluctuations in a time period contemporary with disease outbreaks, and population reductions were likely influenced by disease epidemics that killed susceptible individuals rapidly (Graham et al., 1989; Jacobi, 2000). However, reported fluctuations in Tipu's population were also influenced by: 1) inaccuracy of historical records 2) influxes of Maya who were fleeing Spanish colonization efforts in northern Yucatan, and 3) the tendency of indigenous people to abandon even the least heavily controlled mission towns for un-colonized regions of the frontier zone (Farriss, 1984; Jones, 1998), especially during times of social upheaval and rebellions. In 1618, census records indicate the population of Tipu was 340 (Jones, 1989). In 1622, the population dropped to 30, but the very next year it was back to 340, and 20 years later the population was 1100 (Jones, 1989). It is uncertain whether the very low population in 1622 was due to an epidemic because it could also reflect inaccuracy in census documents or a dispersal event.

In relation to Maya communities that were forcibly relocated by reduction efforts and therefore under direct Spanish control (e.g. Lamanai), population size and health at Tipu was relatively well maintained (Danforth et al., 1997; Jacobi, 2000). In fact, the health and stature data from the Tipu burial sample are very similar to that of the pre-contact Petén Maya. Along with low incidence of anemia, this attests to Tipu's lower population size, and higher degree of isolation (Danforth et al., 1997). Nevertheless, it is important to keep in mind that Tipu was not a closed population (Danforth et al., 1997), and factors listed above have influenced the makeup of the Tipu burial sample.

Comparative Non-elite Samples

Caves Branch Rockshelter

Caves Branch Rockshelter (CBR) is located in the Caves Branch River Valley in the Cayo District of central Belize, which is characterized by rich alluvial plains, tropical

forests and limestone ridgelines with hundreds of caves and rockshelters (Goldstein, 1996; Hardy, 2009). Rockshelters are distinguished from caves based on their exposed chambers and lack of a dark zone (Prufer, 2005; Peterson, 2006). To the west of Caves Branch River Valley is the Roaring Creek Valley, and to the south are the Maya Mountains (Hardy, 2009). Caves and rockshelters in both river valleys were used as early as the Preclassic and Early Classic for Maya cave ritual and burial practices (Wrobel et al., 2009).

All complete vessels recovered at CBR are of Late Preclassic form, and accelerator mass spectrometry (AMS) dates on burials from several locations within the rockshelter indicate the interment of individuals at the site occurred from the Late Preclassic to the Late-Terminal Classic Periods (300 BC - AD 950) (Wrobel et al., 2009). Ceramics indicate that cultural deposits were made from the Middle Preclassic to the Postclassic (100BC - AD 1500) (Glassman and Bonor, 2005; Hardy, 2009). AMS dates and the relatively consistent degree of preservation of human remains suggest burials were not placed throughout the site's entire ceramic sequence (Wrobel, 2008; Wrobel et al., 2009). Prolonged use of a particular cave or rockshelter over time is documented at other caves and rockshelters in western Belize (Peterson, 2006; Prufer, 2005), which suggests that despite any political change that occurred over time, such sites were always important, sacred places to the Maya (Hardy, 2009)

Excavations at CBR began in 1994 and continued until 2009 (Glassman and Bonor, 2005; Wrobel, 2008; Wrobel et al., 2007; Wrobel et al., 2009). Soils in the rockshelter have no clear stratigraphy, and artifacts, human remains and *jute* shells were found in varying concentrations in the majority of contexts, which signifies a long period of soil matrices being mixed by bioturbation and extensive use of the site for human burials (Glassman and Bonor, 2005; Wrobel, 2008). While there were some complete primary burials, they did not have discernible grave outlines and their headings varied (Wrobel, 2008). At CBR, this type of repeated use of the same area for interment suggests the burial sequence occurred over a few generations, and in situ grave goods further suggest the cemetery was used during parts of two consecutive complexes that spanned ~1,000 years (Wrobel, 2008).

The human skeletal remains excavated from CBR represent a Classic period population of rural farmers (Glassman and Bonor, 2005; Wrobel et al., 2007). The consistent non-elite status of individuals buried there over time is inferred from the presence of artifacts typical of a small farming community, including: simply styled ceramic vessels, sherds from utilitarian vessels (Wrobel, 2008), net weights, local fauna, chert flakes and low frequencies of jadeite, obsidian and carved marine shell (Bonor, 2002; Wrobel and Tyler, 2006; Wrobel et al., 2007). There were no polychrome pot sherds, which were typically reserved for elite grave goods, included in burials (Wrobel, 2008). In addition, no elite presence is evident in the valley below the rockshelter until the Late Classic (AD600-800) (Andres and Shelton, 2010; Wrobel et al., 2007; Wrobel et al., 2009). This suggests that in the Caves Branch River Valley, patterns of cave use were not reflective of social status prior to this time period (Wrobel et al., 2009).

Wrobel and colleagues (2009) describe the skeletal sample from CBR as "relatively healthy" based on lack of severe infections, no evidence of trauma, little to no anemia and low caries rates. Both males and females and all age groups, including a large percentage of infants, are represented in the burial sample, which is a demographic pattern typical of pre-industrial societies (Wrobel et al., 2007). Long bones (mostly fragments) from a total of 43 individuals (28 females and 30 males) from the CBR burial sample were available for analysis in this study.

Actun Uayazba Kab (Handprint Cave)

Uayazba Kab is a cave site in the Roaring Creek Valley, to the west of monumental structures of Cahal Uitz Na. The valley is similar to Caves Branch Valley in its topography, ecology, and high frequency of caves (Jordan, 2008). The cave entrance is a rockshelter with twin entrances that are separated by a stalagmite column (Griffith, 1999). Ceramics indicate Late Preclassic (300 BC) use of the cave, but mortuary practices within the cave intensified in the Late Classic. A minimum number of seven individuals were recovered in the Burial Alcove of the cave, three of which were adults (Ferguson and Gibbs, 1999; Gibbs, 1998). Of the three adults, two females met

preservation criteria for analysis in this study: Burials 3 and 4. All human remains were recovered in the Main Entrance chamber below the ground surface and associated with many grave goods including: shell, obsidian, quartz crystal, pyrite, slate, ceramics and lithic material (Gibbs, 1998). These grave goods, lack of cranial and dental modification, and the site's similarities to other rockshelters used for mortuary ritual, suggest individuals buried in Actun Uayazba Kab were non-elites (Wrobel, 2012b). The cave is unique in that it contains one of the most prolific examples of Maya cave art in Belize, which includes pictographs (including negative handprints), petroglyphs, sculpted anthropomorphic faces, and architectural carvings (Bassie-Sweet, 1991; Gibbs, 1998; Helmke and Awe, 1998). Most individuals were buried in flexed positions in simple pits or crypts. The Burial Alcove was likely the primary location for burials because of its interior location and its deeper soil matrix. The two females analyzed from Uayazba Kab showed no significant differences from CBR females in CSG properties of the humerus, femur or tibia (see Results).

Comparative Elite Samples

The elite status of individuals was determined based on their association with monumental architecture, elaborate grave goods, and/or placement in caves that are associated with major centers. The majority of the elite sample used here actually comes from a cave context, which is mostly reflective of differential preservation in the Lowlands. Skeletal remains in dry caves and rockshelters are always best preserved, even when considering individuals buried in tombs built into monumental structures, because the humidity of the region cannot be combated by built structures. Both Maya elites and non-elites honored their ancestors by interring them within architectural features, whether they were residential house mounds or the monuments of major centers. It is thought that this facilitated social definition of one's residence, and for elites, it additionally reinforced an individual's political power, status, and ties to a major center (McAnany, 1998).

For the purposes of this study, i.e. defining a sample of Maya elites that can be compared to individuals at Tipu in order to assess activity patterns in the Colonial Period,

it is assumed that all individuals from Baking Pot, Cahal Pech, and Je'reftheel are elites. However, it is important to consider that grave goods do not always equal social status and several lines of evidence should be used when inferring status. For individuals at Baking Pot and Cahal Pech, this assumption is based on the association of burials with monumental architecture and elaborate grave goods, as well as the status of those sites as major centers of the Belize River Valley during the Late to Terminal Classic Periods (AD 580-900) (Audet, 2006). It should be noted that two individuals analyzed from Baking Pot are considered simple burials with very few grave goods and no evidence of tomb structures. Preliminary tests were conducted to determine whether the three elite samples differed significantly from one another in skeletal robusticity, and no significant differences were detected between males or females for any cross-sectional property of the humerus, femur or tibia (see Results).

The assumption that Je'reftheel cave burials represent elites may also be problematic. Presumably, Maya individuals of all social tiers saw caves as sacred places due to their association in Maya mythology as entrances to the underworld (Griffith, 1999; MacCleod and Puleston, 1978; Prufer, 2005; Prufer and Brady, 2005; Saul et al., 2005). Xibalba is the Maya underworld described in the Popul Vuh. It is depicted as a watery, dark level of the universe. Caves symbolized entrances to this mythological realm (Griffith, 1999; MacCleod and Puleston, 1978; Prufer, 2005). It has also been argued that various cave chambers served as analogs to the multiple "houses" that occurred in the underworld (Tedlock, 1985). Because they were so revered, caves were used by many for religious ceremonies associated with ancestor veneration, birth, death, fertility, and spiritual transformation (Awe, 1998; Bassie-Sweet, 1991; Rissolo, 2003; Stone, 1997; Vogt and Stuart, 2005; Prufer, 2005). However, there is also evidence that certain cave sites came to have more specific meanings and functions among the Maya (Brady and Prufer, 2005; Garza et al., 2002; Glassman and Bonor, 2005; Peterson, 2006; Prufer, 2005; Saul et al., 2005), and there are several lines of evidence that Je'reftheel was a cave primarily used for elite mortuary practice.

Je'reftheel is proximate to the recently documented and highly integrated major centers of Tipan Chen Uitz and Cahal Uitz Na in the Roaring Creek Valley (Andres et al.,

2010; Conlon and Ehret, 1999; Jordan, 2008; Wrobel, 2011). Both of these major centers emphasized and intensified cave ritual during the Late Classic (Andres et al., 2010; Conlon and Ehret, 1999; Jordan, 2008), when Je'reftheel was primarily used for mortuary ritual (Helmke, 2009; Helmke et al., 2012). At Tipan Chen Uitz, the significance of caverns under constructed buildings was emphasized by their use as caches for elaborate prestige items, and at Cahal Uitz Na, a *sacbe* (constructed road) connected the dominant elite residence to a small ritually significant cave (Andres et al., 2010). These major centers were integrated socially, politically, and economically via *sacbeob* (multiple constructed roadways) (Andres et al., 2011a; Wrobel, 2011) and represent a network of elites with close ties to the subterranean parts of the Caves Branch and Roaring Creek Valleys (Andres et al., 2010), which included Je'reftheel. Ethnographic and ethnohistoric accounts provide evidence that cave ritual was a means for individual or corporate groups to claim ties with the land (Jordan, 2008), and that these claims to subterranean sites, symbolic of the underworld, became status-related in the Late Classic (Andres et al., 2011b). It is thought that because newly-arrived elites would not have had longstanding claims to the region, they used the caves there extensively for burial and other rituals as a way to legitimate their newly established political claims to the region (Jordan, 2008). The restricted nature of the cave, artifacts included in burial contexts, and skeletal evidence that individuals at Je'reftheel represent a small family or corporate group, also support the assumption that high status individuals were interred there (Helmke et al., 2012; Wrobel, 2011).

Je'reftheel (Skeleton Cave)

Je'reftheel is a small cave in the eastern hills of the Roaring Creek Valley, in an area known as the southern Roaring Creek Works (Helmke, 2009). It is one of several caves in the area that contain evidence for a coherent regional tradition of cave utilization, however, the nature of its use suggests it was part of the mortuary ritual of a distinct community (Helmke et al., 2012). Most features include commingled human remains, suggesting mortuary behavior similar to that seen in tombs, where individuals

were collected and re-deposited (possibly from other locations) or disturbed to make room for more recent interments (Tiesler, 2007; Wrobel, 2011). The commingling of remains in some areas of the cave may also be due to water activity (Wrobel and Ebeling, 2010). Skeletal remains show no indication of violence or sacrificial practice, and seem to represent a small corporate or family group, based on similarities in cultural modifications and a high rate of congenitally absent 3rd molars (Wrobel, 2011). Strontium isotope analysis indicates they were residents of a nearby site (Wrobel, 2011).

The cave is a single narrow passage that widens into several alcoves and terminates in several chambers (Helmke, 2009). Within the site, 12 distinct features were defined in the 2004 field season, and seven of those contained human remains (Helmke, 2009; Wrobel and Ebeling, 2010; Wrobel, 2011). Of the seven features that include human remains, six provided skeletal material suitable for this study representing 14 females and 22 males. These Features are 1, 4, 5, 6, 7, and 11. All archaeological features at Je'reftheel seem to have been deposited over a short time period (~100-150 years) in the Late Classic (AD550-950), and the cave's primary use was for mortuary practice (Helmke, 2009; Helmke et al., 2012). Whole ceramic *ollas* (pots) of consistent form were the most frequent artifact deposited, and also support the Late Classic date (Helmke, 2009; Wrobel, 2011). Small congregations of people were possible only in Chambers 1 and 2 near the mouth of the cave. This is reflected by larger clusters of artifactual features in these chambers (Helmke et al., 2012). The cave's termini were the preferred places for interment of human remains and very restricted passage ways to these locations would have allowed placement of bodies by only one or a few individuals (Helmke, 2009; Helmke et al., 2012).

Features 1 and 4 (MNI=4) are scatters of disarticulated human remains in Chamber 2. Feature 5 (MNI=6) is a well-preserved group of commingled remains in Chamber 3 associated with a small ceramic *olla*, carved shell *adornos*, a stemmed chert biface, carved shell L-shaped ear adornments (labrets) with greenstone appliques, and two concentrations of perforated Dwarf Olive (*Olivella*) shell tinklers that formed part of a belt and a bracelet. The labrets, bracelet and belt were found *in situ* with a relatively intact burial. Belts of Olive shell tinklers are commonly represented in Mayan

hieroglyphics (Helmke et al., 2012; Wrobel, 2011). Similar artifacts have been found in main burial chambers at Actun Kabul and Actun Tunichil Mucnal, and in special deposits at Pook's Hill (Helmke et al., 2012). Features 6 (MNI=1) and 7 (MNI=3) are clusters of fragmentary human remains interspersed with small ceramic sherds in Alcove 1, and Feature 11 (MNI=1) is a group of scattered human remains and two *ollas* in Chamber 1 (Helmke, 2009). Both males and females, as well as adults and juveniles are represented at Je'reftheel, so there seem to be no restrictions on social groups defined by sex or age interred there (Wrobel, 2011).

Baking Pot

Baking Pot is located on the south bank of the Belize River between the modern towns of San Ignacio and Belmopan, only 10 km away from the site of Cahal Pech (Helmke and Awe, 2008). The site is marked by several core monumental structures and plazas, and monumental groups that are connected by causeways (Helmke and Awe, 2008), as well as hundreds of peripheral smaller monumental structures, administrative buildings and residential structures (Audet, 2002; Audet and Awe, 2004). The site was occupied from the Middle Preclassic (~600-300 BC) into the Early Postclassic (AD1200) (Hoggarth et al., 2008; Audet, 2006), and it served as capital of a small kingdom from AD 250-830 (Hoggarth et al., 2008).

A total of four individuals from the site were preserved well enough for analysis in this study. The features they were associated with include: Structure 209 and Plaza 2 in Group 1, and Structure 190 in Group 2. A causeway connects Groups 1 and 2. At the north end of the causeway in Group 1 is Structure 209, which is associated with two monolithic limestone altars and a fragmentary plain limestone stela (Helmke and Awe, 2008; Audet, 2006). Plaza 2 of Group 1 consists of two pyramidal structures, 5 range structures, 2 ballcourts and a platform (Helmke and Awe, 2008). Another causeway leads south from the southwest corner of Group 2. At its southernmost terminus is Structure 190, which is associated with two plain limestone stelae and a masonry altar that had been covered by more recent construction activity (Helmke and Awe, 2008; Audet,

2006). Structures B1-B4 define the main plaza of Group 2. Along with Structure B3, Structure B4 defines one border of Ballcourt 3 (Helmke and Awe, 2008). Below are descriptions of burials analyzed and their associated structures.

Group 1 Burials:

Structure 209, Burials 3 and 4

Structure 209 includes components dated from the Late Preclassic to the Late Classic (100 BC - AD800) (Audet, 2006). Four people were interred in Structure 209 along the central axis of the platform at its summit (Audet, 2006), but only two individuals, Burials 3 and 4, were preserved well enough for analysis. The structure was made of cut limestone blocks, had plastered floors, and was characterized by a series of elliptical terraces topped with a platform that is similar to platforms dating to the Preclassic known to have been used as spaces for ritual dancing. A short staircase allowed access to the platform from the causeway. Like many Classic period ceremonial complexes, the structure had two altars and a single broken stela.

Burials 3 and 4 were interred in the same small tomb, at the center of the uppermost platform, approximately 3m below the most recently constructed floor of Structure 209. Ceramics within the tomb indicate that the burials date to the Late Classic period (AD 550-650) Burial 3 was a primary burial of a middle adult male (35-50 years at death) placed in an extended position and Burial 4 was a secondary burial. Burial 4 is a partially complete skeleton whose elements were grouped together and placed in a polychrome dish within the tomb at the feet of Burial 3 (Audet, 2006). Grave goods associated with this tomb include: seven vessels, bone hairpins, jade objects including pendants and ear flares, and three obsidian blades (Audet, 2006).

Group 1 Plaza 2, Burial 1

Plaza 2 in Group 1 is bordered on the east and west by two large temples, designated Structures E and B, respectively (Swain, 2005). Burial 1 was uncovered in a 1.5m x 1.5m unit that was laid out along the central axis of Structures E and B. The burial was under three subsequently constructed floors and is considered a "simple" burial,

since no large stones encased it (Swain, 2005). Skeletal remains are those of a young adult male (20-35 years at death) placed in a semi-flexed position. The individual's maxillary incisors and canines each have one round jade inlay. Ceramics associated with the individual suggest a Late Classic Period (AD 590-880) interment (Swain, 2005).

Group 2, Structure 190, Burial 2

Structure 190 formed the southern terminus of Baking Pot's southernmost causeway and its last two construction phases are dated to the Late and Early Classic. The structure was a low platform with a large central altar and a two-room masonry structure made of cut limestone blocks that were mortared together and covered with lime plaster. During Late Classic construction, four individuals were interred within Structure 190 along its central axis (Audet, 2006). Burial 2 is the only burial that fit analysis criteria, and is an adult male of unknown age who was interred with two unslipped ceramic bowls (Audet, 2006).

Cahal Pech (Place of Ticks)

Cahal Pech was a hilltop community at the junction of the Mopan and Macal Rivers, on the west bank of the Macal River, and was made up of several temples, plazas, courtyards, administrative and residential structures, and two ballcourts (Audet, 2006; Garber et al., 2004). Possibly one of the first occupied centers in the Belize Valley, construction began at Cahal Pech in the Preclassic and building activities continued in the Early and Late Classic. Social and political ties to Baking Pot are evident from ceramic assemblages (Audet, 2006). Three individuals interred here were analyzed.

Tolok Burials 2, 4(Individual 2), and 5

The Tolok Group is on the periphery of Cahal Pech's site core. It consists of a group of mounds on a long narrow ridge (Powis, 1992). Ceramics indicate it was occupied from the Preclassic to the end of the Late Classic. Burial 2 was one of five primary burials placed next to a circular Preclassic platform ~5m in diameter. Interment likely occurred in

the Late Classic (Powis, 1992). Burial 2 was a capped cist grave and represents a young adult male (Powis, 1992; Song, 1992). Associated grave goods included shell pendants and a polished jade disk (2cm in diameter). Burial 4 was a simple cist grave that contained two individuals. Individual 1 was placed on top of Individual 2, which had the best skeletal preservation (Powis, 1992). Individual 2 is a middle adult male. Burial 5 was also a simple cist grave containing a middle adult male (Powis, 1992).

Methods

From each sample analyzed, the sex and age of each individual was estimated using techniques described by Bass (1995) and Buikstra and Ubelaker (1994). Pelvic features examined to estimate sex include: the sciatic notch, ischio-pubic ramus, and sub-pubic angle. Skull attributes were used in conjunction with, or in place of, pelvic indicators of sex. These included the relative robusticity features at glabella, the nuchal region, the mental eminence and the mastoid processes. When skeletal elements indicative of sex were too fragmentary or absent, discriminant functions were used to estimate sex from long bone robusticity measurements (Wrobel et al., 2002) (See Table 4.2). These discriminant functions were developed using the Tipu burial sample (Wrobel et al., 2002). Wrobel and colleagues (2002) created functions for more single measurements than listed below, but not all were possible to make on the more fragmentary samples analyzed here. The sex of individuals for which these types of estimates were made was also confirmed using multivariate discriminant functions available at ibetsy.com/bones (Wrobel et al., 2002).

Table 4.2: Single measurements used to estimate sex following discriminant functions created by Wrobel and colleagues (2002)

Element	Measurement
Femur	Subtrochanteric AP diameter Midshaft AP diameter Midshaft circumference
Tibia	AP diameter at nutrient foramen Midshaft AP diameter Midshaft circumference Minimum circumference
Humerus	Midshaft maximum diameter Midshaft minimum diameter Midshaft circumference Deltoid tuberosity diameter Minimum circumference
Radius	Minimum circumference Tuberosity diameter
Ulna	Minimum circumference

The pubic symphysis and auricular surface were the primary skeletal features consulted to estimate age, using the Suchey-Brooks Scoring System (Brooks and Suchey 1990) and Ubelaker's (1989) auricular surface descriptions, respectively. In absence of os coxae, cranial suture closure and tooth wear were considered. In some cases, elements indicative of age were not well enough preserved or associated with a particular individual to make a young, middle, or older adult age estimation. Only young (20-35 years) and middle adults (35-50 years) are represented in skeletal samples analyzed. Since the majority of skeletons analyzed were not complete enough to narrow down age ranges, individuals were placed in one of these two general age categories.

Body size of individuals in this study was estimated when possible, since body size effects expressions of bone functional adaptations (Ruff et al., 1991). When possible, femur, tibia and/or humerus length were measured to estimate stature with formulae developed from a Mesoamerican reference sample (Genoves, 1967), which is the most relevant sample available for pre-contact and Colonial Period Maya populations. Body mass was estimated using discriminant functions created with a pre-historic Native North American reference sample (Daneshvari, 2009) (Table 4.3), as well with the more traditionally used femoral head diameter (Ruff et al., 1991).

Table 4.3: Measurements made for estimating body mass using Daneshvari's (2009) discriminant functions

Measurements for females	Measurements for males
ML width of femoral midshaft Femoral head diameter Humerus epicondylar width Femur length	Femur length Femoral bicondylar breadth Tibia maximum midshaft diameter

3D Image Acquisition

A Nextengine® 3D laser scanner was used to acquire images of all long bones present for each individual in this study. Elements scanned for measurement of CSG were the right and left humeri, femora, and tibiae.

First, all osteometric measurements for stature and body mass estimation described above were made on the actual bones. For better digital visibility, the locations of cross-sections to be measured were then highlighted with chalk. A line of chalk was drawn on the cortex perpendicular to the long axis of the humerus at 35% of length (immediately distal to the deltoid tuberosity), and on the femur and tibia at 50% of length (midshaft). Each bone was mounted with the turntable's arm in the most secure way possible, which means initial scans were made with elements in varied positions. The nature of the apparatus used to secure objects for scanning did not allow all elements to be oriented in a standard way, so for CSG measurements, images were re-positioned in a standard way in 3D space during editing (please see a more detailed description in the CSG measurement section below).

The turntable was placed 6" in front of the scanner and long bones were positioned using the reference camera window in Nextengine's® Scan Studio HD® software (2006-2010) so that the relevant diaphysis segment was visible to the laser scanner. The scanner was set to macro mode and points per square inch were set to the HD range which ensures that all scans were of the highest accuracy (0.127mm) (Figure 4.4).

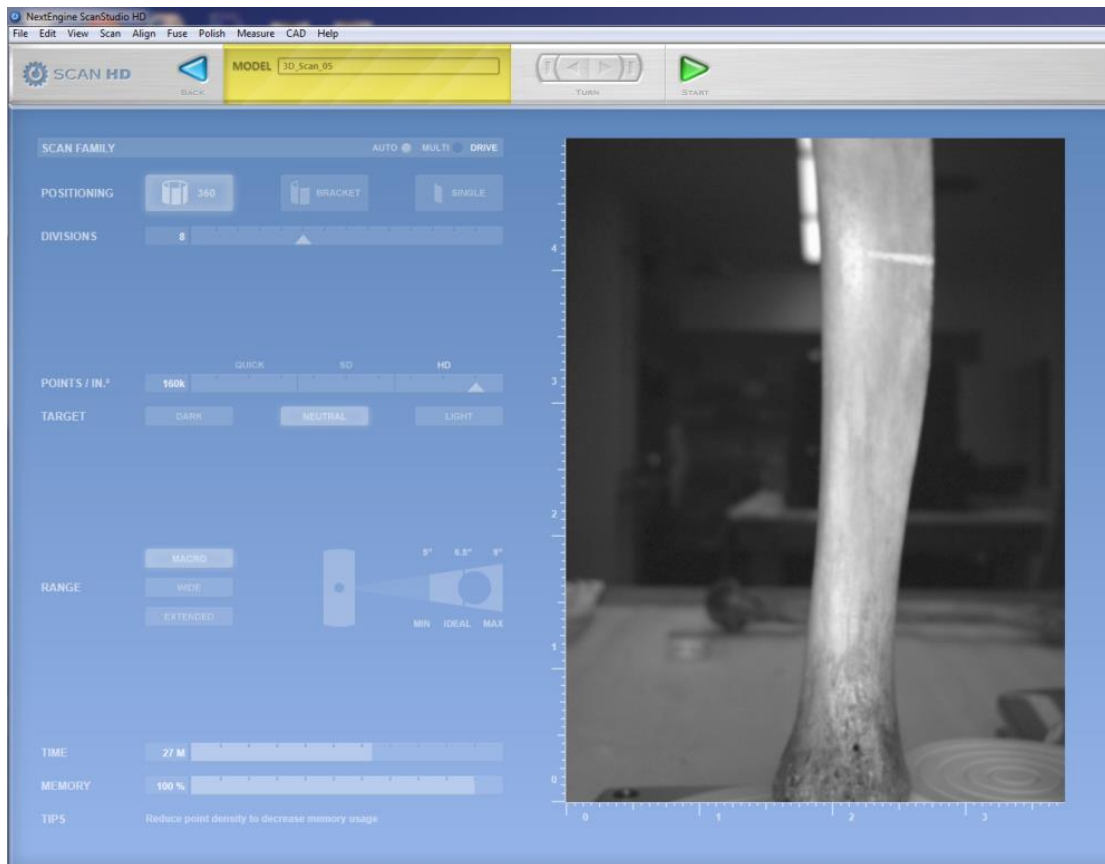


Figure 4.4: Example of ScanStudio's Acquisition Window and Chalk Line Drawn at Midshaft

A recent study demonstrates that these settings are sufficient for creating an accurate two-dimensional image of a long bone cross-section from a three-dimensional model (Davies et al., 2012). Eight divisions were used for all scans, which means for each 360° turn of a long bone the scanner captured eight 3D images of the bone's surface. These eight scans were then "stitched together" to create a 3D reconstruction of the bone using Scan Studio. Finally, images were "cleaned up" by eliminating parts of the turntable and arm that were captured in the scan, and using the Fuse option to eliminate image distortion caused by having several overlapping scans of each long bone's surface. The Fuse option matches up the shared data points in each of the eight scans made to create a smooth, aggregate 3D image. After editing, all 3D images were stored on external hard drives for further measurements.

Measurement of Cross-sectional Geometry

Measuring the cross-sectional properties of long bones from their 3D replicas involved re-orientation of each bone in a standard way (Ruff, 2002) and conversion of .scn image files produced by ScanStudio® to .xyz files. These .xyz files were then run through the AsciiSection program (Davies et al., 2012) to attain values of I_{max} , I_{min} , and TA . Because 3D models only re-create the outer surface of a long bone, and do not account for dimensions of the medullary cavity, cross-sectional properties were inferred from long bone diaphyseal shape, following Shaw and Stock (2009). I_{max} and I_{min} are maximum and minimum second moments of area, and are correlates of maximum and minimum bending strength, respectively. These values were summed to get J , which is the polar second moment of area of a cross-section indicative of torsional and bending rigidity (Ruff et al., 1993). The ratio of I_{max}/I_{min} was also considered as a measure of cross-sectional shape where a ratio of less than 1.5 is typical of a more circular cross-section (Ruff and Larsen, 2001). Values for total subperiosteal area (TA) are an external quantification of combined cortical bone and medullary area, and are indicators of overall long bone robusticity. While there are advantages to measuring the true cross-sectional dimensions of a long bone, meaning they consider cortical thickness and the size of the medullary cavity (Sparacello and Pearson, 2010), methods that only measure the outer dimensions of a cross-section have been shown to be comparable for inferring biomechanical properties of long bones (Davies et al., 2012; Shaw and Stock, 2009; Sparacello and Pearson, 2010; Stock and Shaw, 2007). It should also be noted that for the majority of long bones in the samples analyzed here, it was only possible to measure outer dimensions of the diaphysis because the original shape of the medullary cavity was not often well enough preserved due to taphonomic processes.

Long bone images were oriented using the CAD feature of ScanStudio, following planes described by Ruff (2002) so that each cross-section measured was perpendicular to the long axis of the element. Each humerus, femur and tibia scanned was oriented so that the top of the image was the proximal end and the bottom of the image was the distal end.

Each long bone was oriented in a postero-anterior view, where the image's posterior surface was facing the viewer and the anterior surface was facing away from the viewer.

Because most elements scanned in the study were not complete, the standard measuring procedures of the AsciiSection program (Davies et al., 2012) had to be altered so that the locations of cross-sections to be measured could be specified from the fragment's most distal point (rather than as a percentage of whole bone length) (Davies, personal communication). Each .scn image file was opened in Rapidform Explorer 64 (2011) so that linear measurements could be made from the most distal point of the image to the cross-section of interest. Once the locations of cross-sections were specified for each model, original .scn files were converted to .xyz files in ScanStudio®. Image files created by ScanStudio® are point clouds, where each point has an x -, y -, and z -coordinate and is connected to all points surrounding it with polygons. The polygons among all the points create the 3D model of a bone's periosteal surface. An .xyz file is a list of all the point coordinates that make up an image.

Cross-sections were evaluated using AsciiSection, a custom built software written in c++ with bash script (Davies et al., 2012). To measure a given cross-section for I_{max} , I_{min} , J , and TA , the program "split" the .xyz file by selecting all x -, y -, and z -coordinates in the model that had z -coordinates within the range specified (by the measurement of each cross-section's distance from the most distal point of the image). This created a "slice" of the image's point cloud that was 1mm thick. Then, z -coordinates were discarded so that the very thin cylinder of a bone's cross-section was collapsed into a 2D outline of the bone's periosteal shape. The x - and y -coordinates of these shapes were then sorted into order in a clockwise direction around the periosteal contour, and CSG properties were calculated based on formulae for solid polygons (Davies et al., 2012).

Statistical Analyses

The first analyses performed tested for the effects of body size and age on the cross-sectional properties of individuals from all burial contexts because both of these factors have been shown to have significant influence on long bone dimensions (Weiss,

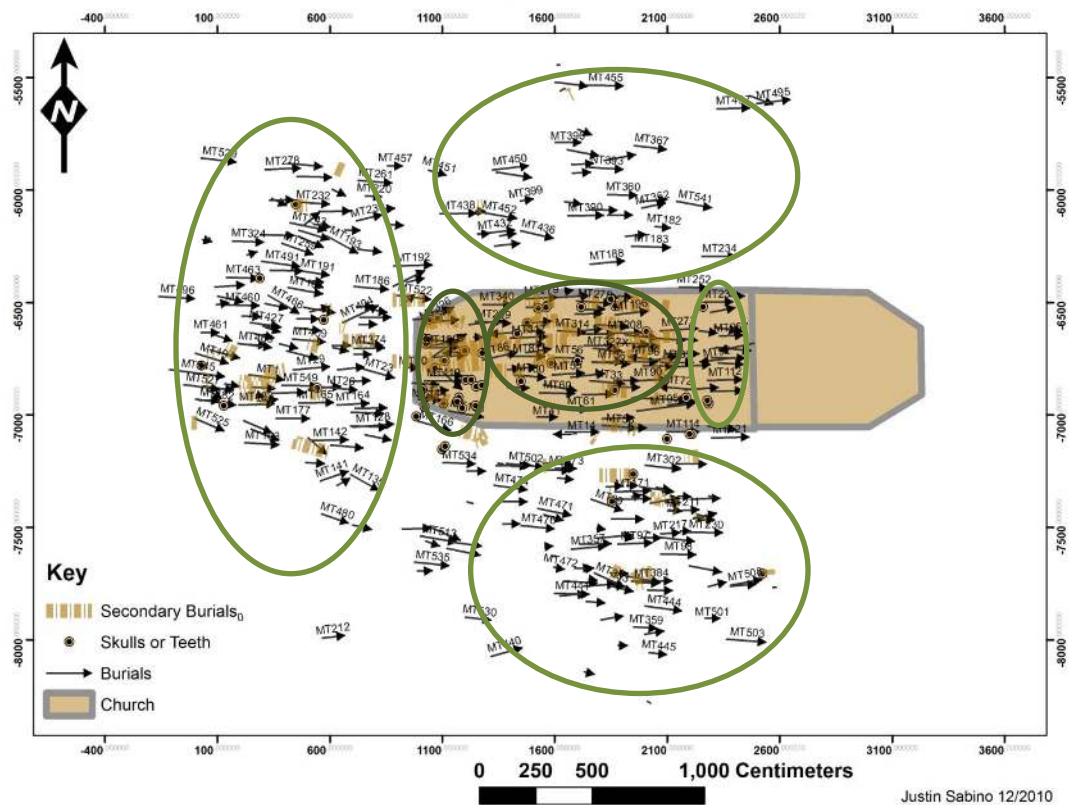
2004; Baker and Pearson, 2006). Spearman's Rho correlations (r_s) and R^2 values were used to assess the effects of body size on CSG properties, and summary statistics for body mass and stature estimates were inspected to assess the amount of variation in body size of the total sample (elites, non-elites and Tipu Maya). Analysis of Covariance (ANCOVA) was used to test for variation in body mass and stature by burial location at Tipu (inside the church walls vs. outside). Two-sample t-tests were used to test for significant differences in the CSG of individuals from young vs. middle adult age ranges. Since two different methods were used to estimate body mass (Daneshvari, 2009; Ruff et al., 1991), Spearman's Rho correlations between stature estimates and both body mass estimates were examined to determine: 1) whether body mass estimates based on a more disparate reference sample correlated with stature estimates developed for Mesoamerican populations, and 2) whether both types of body mass estimates produced similar results.

Box-plots were first consulted to assess patterns of long bone robusticity among individuals of all burial contexts analyzed here. Where major differences were observed among burial groups for a particular variable, Mann-Whitney U tests were used to test for significance, due to relatively small sample sizes. Several combinations of all burial groups were analyzed in this way. First, variation among individuals interred in elite contexts was assessed to determine whether there were great disparities in CSG among elite sites, and the same was done for individuals from non-elite contexts. Then, elites and non-elites were plotted together to identify any major differences in CSG between these Maya of different social strata.

The next step was to assess CSG variation among burial groups only at Tipu. General comparisons of burial groups inside and outside the church walls were made, as were comparisons of more specific burial clusters. Burial groups inside the church included one inside the church at the front (where there is a row of burials bordering the altar), a cluster of burials inside the church at the center of the nave, and a cluster inside the church at the back of the nave. Outside burial groups include clusters to the north, west and south of the church structure (Figure 5). Because very few differences were observed in comparisons of general burial locations inside and outside the church walls, elites and non-elites were examined in relation to the more specific burial clusters at Tipu

to investigate patterns in CSG properties among pre-contact elites, non-elites and Colonial Period burial samples. For each of the within status group analyses listed above, CSG values were compared between right and left elements using Mann-Whitney U tests to determine whether any cross-sectional properties exhibited significant asymmetry. Statistical analyses were performed primarily in SAS 9.2 (2009). The production of box-plots for expedient visual comparisons was done in Minitab (2007). Since there was pronounced sexual dimorphism evident for the majority of cross-sectional properties of the femur, tibia and humerus, all testing was done for males and females separately.

Figure 4.5: Tipu Site Diagram (created by J. Sabino) with Specific Burial Clusters Indicated



Results

Effects of Body Size and Age

Spearman's Rho Correlations (r_s) and R^2 values for correlation between body size (estimated by both body mass and stature) indicate generally weak correlations between body size and cross-sectional properties (Tables 4.4 and 4.5). Since this is an unusual result, Spearman's Rho correlations among all cross-sectional properties served as a test of data quality. As would be expected, measures of J and TA , correlated very well (0.97-0.99) (Tables 4.6 and 4.7), and summary statistics for body mass and stature (for both males and females) indicate low variance for both variables, which indicates the samples of Maya studied here represent a rare case of homogeneity in body size among males and females. In order to maximize sample sizes, and due to these low effects of body size on CSG coupled with the scarcity of lower limb long bones complete enough for length measurements, size standardization of cross-sectional variables was not performed. Correlations between both methods used to estimate body mass and stature also had very low Spearman's coefficients (0.13-0.24 for females, and 0.15-0.30 for males). Neither body mass estimate, obtained from femoral head diameter (Ruff et al., 1991) and Daneshvari's (2009) discriminant functions, correlated well with stature estimates. Only body mass estimates from femoral head diameter are reported below.

Table 4.4: Spearman's Correlation Coefficients (r_s) and R^2 values for CSG properties and body size - males (total sample)

	n=34	Femur			Tibia			Humerus		
		I _{max} /I _{min}	J	TA	I _{max} /I _{min}	J	TA	I _{max} /I _{min}	J	TA
Body Mass	r_s	0.43	0.13	0.15	0.27	0.49*	0.39*	0.01	-0.07	-0.05
	R^2	0.168	0.001	0.004	0.165	0.245*	0.171*	0.012	0.006	0.008
Stature	r_s	-0.25	0.13	0.11	0.09	0.05	0.04	-0.05	0.11	0.08
	R^2	0.158	0.016	0.015	0.008	0.024	0.010	0.008	0.001	0.001

-body mass estimates from femoral head diameter (Ruff et al., 1991)

-stature estimates from Genoves (1967) formulae (femur or tibia length)

* indicates significant p-values

Table 4.5: Spearman's Correlation Coefficients (rs) and R² values for CSG properties and body size - females (total sample)

	n=17	Femur			Tibia			Humerus		
		I _{max} /I _{min}	J	TA	I _{max} /I _{min}	J	TA	I _{max} /I _{min}	J	TA
Body Mass	r _s	0.05	0.39	0.41	0.14	0.43	0.36	-0.15	-0.16	-0.14
	R ²	0.011	0.053	0.054	0.039	0.121	0.116	0.038	0.048	0.031
Stature	r _s	-0.06	0.78*	0.80*	-0.31	0.41	0.41	-0.13	0.41	0.43
	R ²	0.014	0.583*	0.582*	0.148	0.098	0.217	0.042	0.155	0.132

-body mass estimates from femoral head diameter (Ruff et al., 1991)

-stature estimates from Genoves (1967) formulae (femur or tibia length)

* indicates significant p-values

Table 4.6: Spearman's Correlations (rs) among CSG Properties - males (total sample)

n=34	I _{max} /I _{min} x J	J x TA	TA x I _{max} /I _{min}
Femur	0.24	0.99*	0.20
Tibia	-0.32	0.97*	-0.48*
Humerus	-0.25	0.99*	-0.33

* indicates significant p-values

Table 4.7: Spearman's Correlations (rs) among CSG Properties - females (total sample)

n=17	I _{max} /I _{min} x J	J x TA	TA x I _{max} /I _{min}
Femur	-0.13	0.98*	-0.17
Tibia	-0.23	0.97*	-0.35
Humerus	-0.34	0.99*	-0.37

* indicates significant p-values

Table 4.8: Summary Statistics: Body Mass from Femoral Head Diameter and Stature (total sample)

	Females (n=47)				Males (n=63)			
	Mean	Median	Std. Deviation	Std. Error	Mean	Median	Std Deviation	Std. Error
BM	58.68	58	3.74	0.54	62.52	63	3.55	0.44
stature	151.55	152	3.46	0.50	161.95	161	4.33	0.56

-body mass estimates from femoral head diameter (Ruff et al., 1991)

-stature estimates from Genoves (1967) formulae (femur or tibia length)

Low R² values of ANCOVA tests for variation in body size by general burial location at Tipu (inside vs. outside the church walls) indicate body mass and stature, among both males and females, do not vary significantly by burial location (Tables 4.9 and 4.10). This finding is consistent with other studies that compared long bone robusticity indices among burial groups at Tipu. Neither osteometrics of long bone dimensions (Cohen et al., 1989; Wrobel, 2003) nor CSG (Armstrong, 1989) tend to suggest great differences in body size between males or females buried inside the church structure versus outside.

Table 4.9: ANCOVA test for variation in body mass by burial location at Tipu - males inside (n=9) vs males outside (n=8)

	Femur		Tibia		Humerus	
	J	TA	J	TA	J	TA
F	0.232	0.206	0.010	0.0001	0.003	0.0009
Pr > F	0.0498	0.0769	0.7172	0.9677	0.8612	0.9230

Table 4.10: ANCOVA test for variation in body mass by burial location at Tipu - females inside (n=5) vs females outside (n=5)

	Femur		Tibia		Humerus	
	J	TA	J	TA	J	TA
F	0.057	0.028	0.110	0.007	--	--
Pr > F	0.7593	0.8314	0.4660	0.8519	--	--

Only young (20-35 years) and middle (35-50 years) adults are represented in samples analyzed. Two-sample t-tests between young and middle adults indicate there are no significant differences between age groups for cross-sectional properties (Table 11). Young adults do not differ significantly from middle adults in the cross-sectional properties of the femur, tibia, or humerus (p-values=0.081-0.782), therefore the effects of age on long bone robusticity appear to be minimal in these samples.

Table 4.11: T-tests for effects of age on CSG (young adult vs. middle adult age groups)

n=82	Femur			Tibia			Humerus		
	Imax/Imin	J	TA	Imax/Imin	J	TA	Imax/Imin	J	TA
t	0.64	0.76	0.84	1.77	0.28	0.45	0.36	0.32	0.38
p-value	0.527	0.451	0.403	0.081	0.782	0.656	0.720	0.748	0.707

Burial Group Comparisons

Mann-Whitney U tests detected relatively few significant differences among burial groups. Therefore, it was necessary to evaluate the statistical power of t-tests performed. Table 4.12 illustrates that even at a 10% level of significance, the small sample sizes of burial groups compared create relatively high risks of committing Type II errors. No statistical power calculated was greater than the acceptable value of 0.80 for 5%, 8%, or 10% levels of significance. All t-tests were performed at both 95% and 90% confidence levels, however, tests at 90% confidence did not produce any additional significant results. For this reason, the following sections report p-values for inter-group

comparisons at the 95% confidence level, as well as non-significant trends observed from box-plots.

Table 4.12: Statistical Power of T-tests

Comparison	alpha=0.05		alpha=0.08		alpha=0.10	
	Males	Females	Males	Females	Males	Females
Elites - Non-elites	0.59	0.46	0.68	0.56	0.72	0.61
Tipu: Inside-Outside	0.53	0.47	0.63	0.60	0.68	0.62
Tipu Inside - Elites	0.65	0.38	0.73	0.48	0.77	0.54
Tipu Outside - Elites	0.49	0.46	0.59	0.56	0.64	0.61
Tipu Inside - Non-elites	0.66	0.47	0.75	0.57	0.79	0.62
Tipu Outside - Non-elites	0.50	0.60	0.60	0.69	0.65	0.73

- power values attained from Piface 1.76 (Lenth 2006-2009)

Characterizing Elites and Non-elites

Recall that individuals analyzed from elite contexts came from the following sites: Jereft'heel (JH), Baking Pot (BP), and Cahal Pech (CP). Non-elite comparative samples analyzed were from Caves Branch Rockshelter (CBR) and Uayazba Kab (UK). Elite and non-elite samples were first analyzed for within group variation. Comparisons of females interred at CBR and UK showed no significant differences in any CSG property (p-value range: 0.089-0.275), so individuals from the two non-elite burial contexts did not vary significantly in robusticity of the humerus, femur or tibia. When comparing individuals from elite contexts, no significant differences were observed among males at JH, BP or CP (p-value range: 0.071-0.264). Because only one female is represented at BP, and no females were analyzed from CP, comparison of females at JH to other elite sites was not possible.

Tests for asymmetry in CSG properties showed no significant differences between right and left elements for any cross-sectional property of the femur, tibia or humerus among males or females for which both right and left elements were preserved (p-value range: 0.139-0.932). Neither elite, nor non-elite males or females demonstrate significant asymmetry in CSG properties. Because no asymmetry was detected in CSG properties, values for right and left elements were combined in all subsequent analyses to increase sample sizes and the power of statistical analyses.

Observation of box-plots indicates that sexual dimorphism is pronounced for both elites and non-elites in measures of cross-sectional robusticity and shape. The exception to this is femur I_{max}/I_{min} , where mean values suggest more circular femoral cross-sections across sex and status groups (Appendix 3A). Although results are not significant, elite males tend to be slightly more robust than non-elite males in J and TA of all three elements, and non-elite females are most distinct from elite females in the greater AP expansion of the tibia among non-elites (Appendix 3A). Non-elite males and females actually tend to be more similar in tibia I_{max}/I_{min} , with ratios between 2 and 2.4, indicating much greater antero-posterior (AP) expansion of the tibia than observed among elite females, whose mean tibia I_{max}/I_{min} ratio of 1.8 indicates a more eurycnemic (triangular) cross-section.

Mann-Whitney U tests for significant differences between elites and non-elites detected no significant differences in J , TA , or I_{max}/I_{min} between males of different social strata. Female elites and non-elites were significantly different in femur I_{max}/I_{min} ($p=0.015$), femur TA ($p=0.035$), and tibia I_{max}/I_{min} ($p=0.042$). Non-elite females had significantly lower mean femur I_{max}/I_{min} and femur TA , and elite females have lower mean tibia I_{max}/I_{min} than non-elite females. In sum, elite females have significantly greater mean femur I_{max}/I_{min} and femur TA than non-elite females, but non-elite females have significantly greater tibia I_{max}/I_{min} than elite females. Elite and non-elite males are more homogenous in skeletal robusticity.

Characterizing Tipu

The burial sample at Tipu was first examined for asymmetry and sexual dimorphism in cross-sectional properties. Then, differences between the general burial groups, located inside and outside the church walls were examined. Since no significant differences between these generalized burial groups were detected ($p=0.122-0.869$), the sample was further subdivided into more specific burial groups to look for trends in subsample variation. Recall that burial groups inside the church include: inside the church at the front (where there is a row of burials bordering the altar), a cluster of burials inside

the church at the center of the nave, and a cluster inside the church at the back of the nave. Outside burial groups include clusters to the north, west and south of the church structure (Figure 4.5 above).

Mann-Whitney U tests for asymmetry between cross-sectional properties of right and left elements did not produce any significant differences for Tipu burials as a whole or for inside and outside burial groups separately, so all subsequent analyses were done with right and left elements combined. One-way ANOVA tests for sexual dimorphism indicate that males and females at Tipu, from both inside and outside burial groups, are significantly different in femur, tibia and humerus *J* and *TA* (p-values=0.005-0.006). However, *I_{max}/I_{min}* values for all three elements showed no significant sexual dimorphism. Box-plots also show that *I_{max}/I_{min}* values are very similar across both sex and burial groups for all three elements analyzed (Appendix 3B and 3C). This suggests that sexual dimorphism in *robusticity* exists at Tipu, but there is little sexual dimorphism in the cross-sectional *shapes* of elements. *I_{max}/I_{min}* values suggest both males and females at Tipu, regardless of burial location tend to have fairly circular femora and humeri cross-sections, and both males and females have marked AP expansion of the tibial diaphysis.

Box-plots (Appendix 3B) also show that males buried inside the church walls tend to have more robust tibiae than males buried outside (both in *J* and *TA*), and females buried inside tend to have more robust humeri (in *J* and *TA*) than females buried outside. However, Mann-Whitney U tests detected no significant differences between male or female burial groups inside versus outside the church walls.

Characterizing Tipu Continued: Analysis of more specific burial clusters

Females inside the church at the front and females outside the church in the northern burial group consistently have the lowest means for tibial *J* and *TA* (Appendix 3C), and these results are significant (p-value range: 0.004-0.015). The outside northern burial group also has the significantly lowest mean for humeral *J* and *TA* (p-value range: 0.004-0.015), and a marginal p-value for lowest mean femoral *TA* (p=0.052) of all female

burial groups at Tipu. Although not statistically significant, these groups (outside northern and inside front) also have the highest means for tibial *I_{max}/I_{min}* (Appendix 3C). In other words, females inside the church near the altar and females in the outside northern burial group tend to have less robust femora, tibiae and humeri than all other females at Tipu, but they have more AP expanded tibiae than all other Tipu females. Cross-sectional shapes of the femur and humerus are homogenous among all Tipu females.

Although most are not significant, some trends were also visible among males of different burial groups at Tipu. Humeral *J* and *TA* for males from burial clusters inside the church consistently decrease from inside back to inside center to inside front burial groups (Appendix 3C), but p-values for comparisons of humeral robusticity between males from inside back and inside front burial clusters were not significant (p=0.084-0.086). Males at the back of the church have the lowest mean humeral *I_{max}/I_{min}* of all other male burial groups, but the highest mean tibia and humeral *J* and *TA*. Among all males at Tipu, mean humeral *J* and *TA* is lowest for males at the front of the church. Males from the inside back burial cluster have significantly lower mean humeral *I_{max}/I_{min}* than the central burial cluster (p=0.022), but not the front burial cluster. Femur and tibia cross-sectional properties tend to be similar among all Tipu males (with the exception of males buried inside the church at the back who, again, have the highest mean humeral and tibial *J* and *TA*, but not significantly so).

I_{max}/I_{min} values of femora indicate circularity of the femoral cross-sections (ratios range from 1.2-1.4), and AP expanded tibiae (ratios range from 2-2.5) for both males and females among all burial groups. *I_{max}/I_{min}* ratios for humerus cross-sectional shape among all Tipu females have a relatively restricted range (1.35-1.7), in comparison to Tipu males, who vary between 1.24 and 1.84 (Appendix 3B). It is males in the outside southern burial group who deviate most from humeral circularity (mean *I_{max}/I_{min}* = 1.84).

Tipu vs. Elites and Non-elites

Finally, Tipu burial groups, elites and non-elites were plotted together to identify how variation in the two pre-contact groups of high and low status related to variation observed at Tipu (Appendix 3C). For the most part, male and female non-elites fell within the same range of variation as most burial groups at Tipu in cross-sectional measures, but elites tended to have higher means for all cross-sectional properties.

Tipu females in the outside northern burial group and females inside the church at the front maintain the lowest mean femur, tibia and humeral *J* and *TA* of all Maya females. One-way ANOVA indicated that tibial *J* and *TA* ($p=0.002$ and 0.001 respectively) and humeral *J* ($p=0.015$) were significantly lower for females in the outside northern burial group than for all other Maya females. Femoral *J* for the same burial group produced a marginal p -value ($p=0.055$) for the same comparison, but the outside northern burial group was significantly lowest in femur *TA* ($p=0.029$). Although not significant, elite females and Tipu females from the inside center burial cluster have the highest mean femoral *J* and *TA* (Appendix 3C). Elite females have significantly higher mean femoral *Imax/Imin* ($p=0.035$) than all other Maya females, but maintain the lowest mean tibial *Imax/Imin* of all other female groups. Tipu females inside the church in the front burial cluster and in the outside northern burial group maintain the highest mean tibial *Imax/Imin* of all Maya females. Non-elite females have the highest mean humeral *Imax/Imin* of all other female groups, and females at the front of the church inside and those in the outside northern burial group maintain the lowest humeral *Imax/Imin* of all Maya females. In general, females in the outside northern and inside front burial groups tend to be the most gracile of all Maya females in all three elements, but have the most AP expanded tibiae, indicating greater mobility. Elite females are generally most robust, but have the least AP expanded tibiae, while non-elite females stand out in having humeral cross-sections that deviate the most from circularity.

Elite males have the highest mean femoral and tibial *J* and *TA* of all Maya males, but are most similar in lower limb cross-sectional robusticity to males from the burial cluster at the back of the church. One-way ANOVA indicated that elite males and males

from the inside back burial cluster vary significantly from all other male groups in tibial *J* and *TA* ($p=0.007-0.015$). Humerus *J* and *TA* are fairly homogenous among all Maya males. However, males from the inside front burial cluster at Tipu maintain the lowest mean humeral *J* and *TA* of all male groups and males from the inside back burial cluster maintain the highest mean. All samples of Maya males are homogenous in tibial *Imax/Imin*. Tipu males from inside burial clusters at the front and back have the lowest mean humeral *Imax/Imin*, while all other males are fairly homogenous in all other cross-sectional properties. Elite males and males from the inside back burial cluster have the most robust tibiae, and males from the inside front burial cluster have the least robust humeri.

Discussion

Recall that this study attempted to answer three main research questions and generated three main hypotheses (Table 4.13) in order to characterize observed patterns of variation in CSG among burial groups at Tipu.

Table 4.13: Research Questions and Related Hypotheses

Question	Hypothesis
1) Are there differences in the cross-sectional morphology of upper and lower limb long bones between pre-contact elites and non-elites?	1) There will be distinct differences between elites and non-elites in the CSG of the humerus, femur and tibia due to their very different lifestyles and activity patterns (Adams, 1970; Chase and Chase, 1992; Maggiano et al., 2008).
2) Are there significant differences among burial groups at Tipu, and therefore some evidence of a social structure where activity patterns varied among status groups?	2) CSG will be homogenous among males and females at Tipu because previous studies found no distinct differences in skeletal robusticity among burial groups there (Armstrong, 1989; Wrobel, 2003).
3) How do the long bone cross-sectional properties of people interred at Tipu compare to pre-contact Maya at opposite ends of the Classic/Postclassic social hierarchy?	3) General homogeneity in robusticity among Tipuans and the presence of more robust males inside the church structure (Wrobel, 2003) implies the Tipu Maya will more closely resemble pre-contact non-elites in CSG properties of the upper and lower limb.

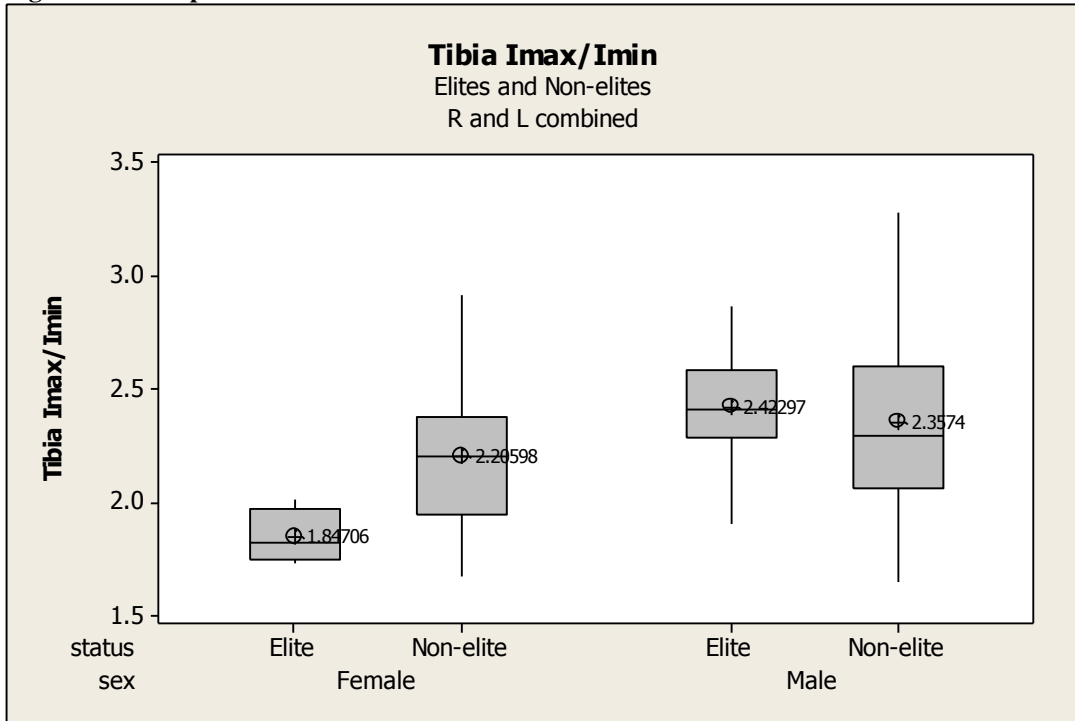
Elite and Non-elite Females

The hypothesis that pre-contact female elites and non-elites had different lifestyles based on their different social status is supported only by the cross-sectional shape of the tibia. Non-elite females have significantly greater AP expanded tibiae, which indicates that they were more mobile than elite females (Figure 4.6). Female non-elites actually had tibial cross-sectional shapes most similar to those of non-elite males (Figure 4.7). This AP expansion of non-elite female tibiae, but not femora, signifies more frequent walking because the orientation of major muscle groups associated with normal gait across the knee joint generate large AP bending loads and relatively little ML bending loads when walking (Ruff, 1987). Running or traversing rugged terrain would also result in AP expansion of femora (Ruff, 1987), which was not observed. Greater mobility among female non-elites is expected because they were involved in gathering jungle resources and would likely have walked long distances to do so (Sharer, 1996). Lack of femoral AP expansion among females at CBR suggests that their travel was generally restricted to the less rugged terrain of the Caves Branch River Valley.

The femora of elite females were significantly more robust than those of non-elite females. However, lack of corresponding AP expansion of the tibia, and a similar, though non-significant, difference in femoral robusticity between elite and non-elite males, suggests a nutritional difference rather than an activity-based difference. The humeri, femora, and tibiae of elite males tended to have greater torsional and bending strength than those of non-elite males (Appendix 3A). It is likely that the greater robusticity of elite males in general and the greater femoral robusticity of elite females is due to the better nutritional status of the higher status group (Cucina and Tiesler, 2007; White et al., 1993; Wright, 1994). There is skeletal evidence that Maya elites had access to a greater variety of resources, better nutrition, and therefore would have had greater long bone robusticity overall (Cucina and Tiesler, 2003; 2007; Somerville et al., 2013; White et al., 1993; Wright, 1994). The conclusion that the female non-elites in this study were more mobile than female elites is actually supported further when it is considered that non-elite

females had the same nutritional status as non-elite males, yet still demonstrated greater AP expansion of the tibia than the better nourished elite females (Figures 4.6 and 4.7).

Figure 4.6: Box-plots of Tibia I_{max}/I_{min} for Elite and Non-elite Males and Females



Tibial Cross-Sectional Geometry : Elites vs. Non-Elites

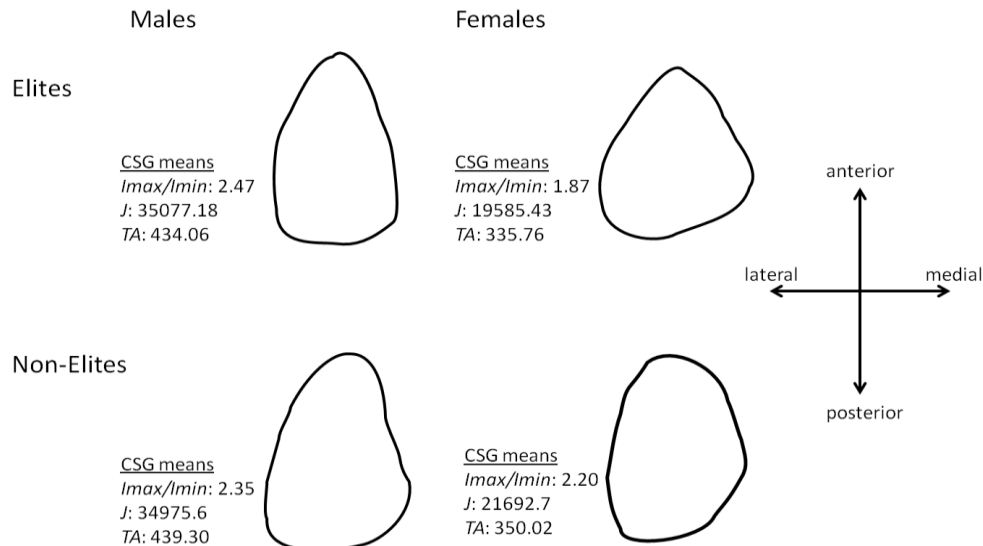


Figure 4.7: Diagram of Typical Cross-sectional Shapes of Elite and Non-elite Males and Females

Elite and Non-elite Males

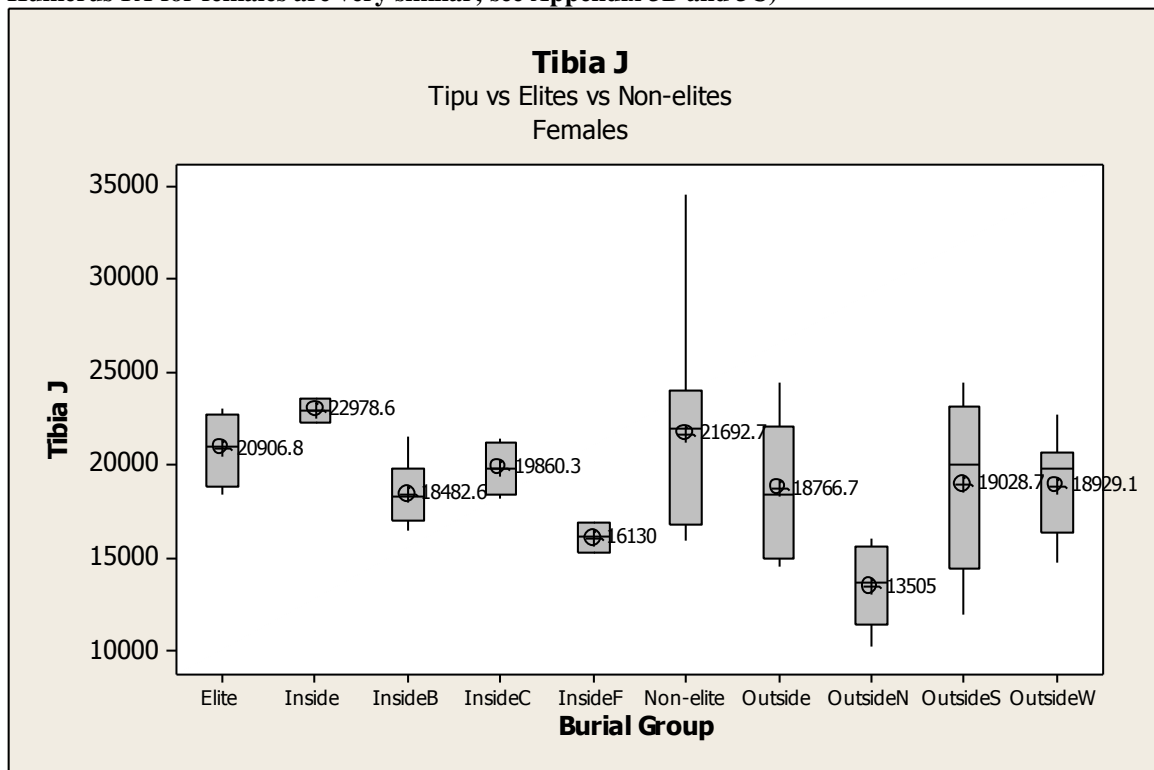
The hypothesis that pre-contact elites and non-elites had different lifestyles and therefore activity levels is not supported for males. It is possible that even though the specific activities of elite males may have been different from those of non-elite males (Adams, 1970; Chase and Chase, 1992), the activity *levels* of the two social groups did not differ significantly. If so, differences reflective of different activity patterns could not be detected in the CSG of upper and lower limbs. Non-elites were presumably engaged in more manual labor associated with the construction needs of a community, planting and harvesting milpas, and hunting and gathering in surrounding jungle and river ecosystems (Redfield and Villa Rojas, 1964; Sharer, 1996). Elite males may have participated in hunting activities of their own (Jones, 1998) that were similar to those of non-elites. Other important factors governing the activity patterns of elite Maya males include: the physical training required for warfare, training required for the ball game, and evidence that Maya elites traveled between major centers via watercraft, or on foot (Jones, 1998). The combination of such training and mobility patterns may explain the similarity in elite and non-elite males observed here.

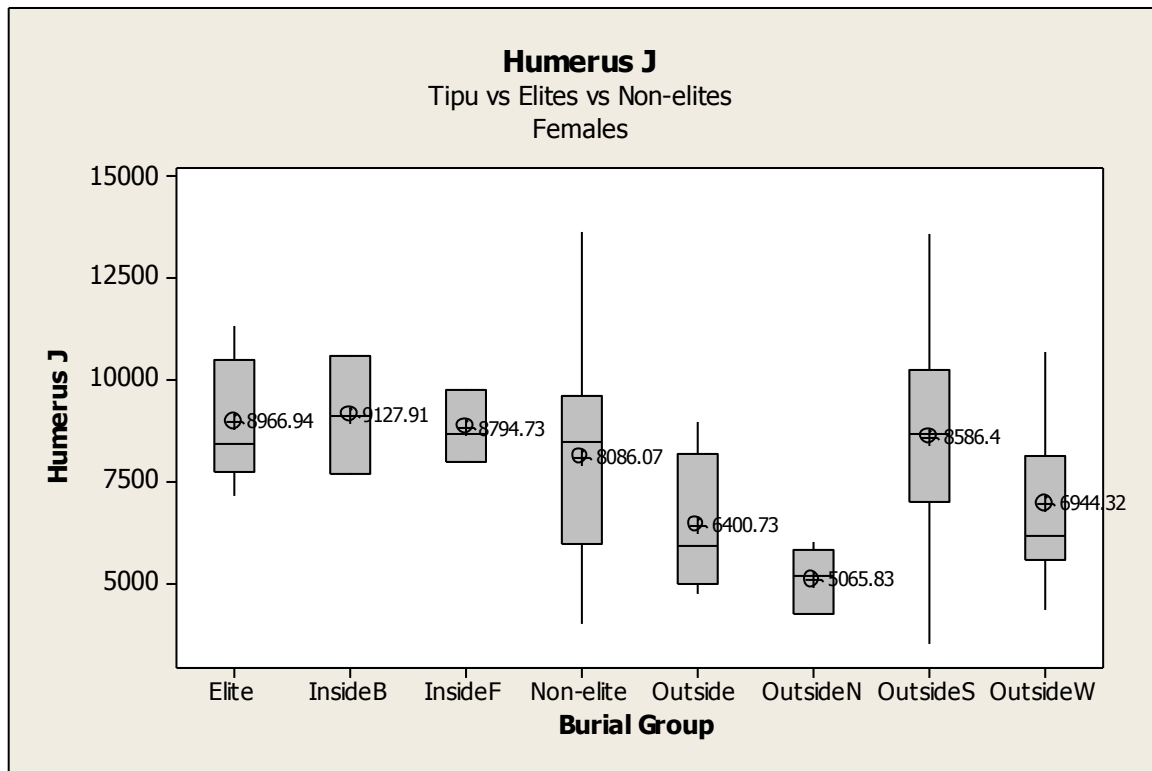
Burial Groups Inside and Outside the Church Structure at Tipu

When Tipu individuals were analyzed by general burial location, inside versus outside the church structure, no significant differences in the torsional strength, bending strength, or the cross-sectional shape, of the humerus, femur or tibia were detected for males or females. There was also no humeral asymmetry detected among males or females buried inside the church structure versus outside, so no patterns of unilateral versus bilateral upper limb use distinguished individuals by burial placement. Therefore, as previous studies have concluded (Armstrong, 1989; Wrobel, 2003), the strength and shape of upper and lower limb long bones appear homogenous among Maya males and females interred at Tipu.

Further exploration of this homogeneity in CSG properties with more specific burial clusters (inside front, inside center, inside back, outside northern, outside western and outside southern) (Figure 4.5) also tends to support the hypothesis that males and females at Tipu were homogenous in CSG properties of the upper and lower limb regardless of burial placement. However, notable exceptions were observed for females. Females in the burial cluster at the front of the nave, bordering the altar, and females in the burial cluster outside the church structure in the *atrio* (to the north) were generally more gracile than all other females at Tipu. Females buried in the *atrio* also had significantly more gracile humeri and tibiae (Figure 4.8). This suggests some females at Tipu engaged in less manual labor. However, they were not necessarily less mobile because they maintained AP expansion of the tibia. Because females buried near the altar and in the *atrio* were similar in CSG properties of the tibia, and females buried in the *atrio* had very gracile humeri in comparison to all other females at Tipu, it is speculated that the *atrio* may have been another "high status" burial location, especially considering that space inside the church near the altar was limited.

Figure 4.8: Box-plots of Tibia and Humerus *J* for Females of all Burial Groups (plots of Tibia and Humerus *TA* for females are very similar; see Appendix 3B and 3C)





Tipu males, regardless of burial placement, remained more homogenous in the cross-sectional shape of the humerus, femur and tibia. There is some evidence that more gracile males were buried inside the church, but the pattern was not as distinct as the differences observed for females. However, Tipu males and females did demonstrate an interesting pattern of sexual dimorphism in CSG properties. Sexual dimorphism in the torsional and bending strength of the humerus, femur, and tibia is significant, but the cross-sectional *shapes* of these elements did not differ significantly between males and females (Appendix 3B). Therefore, while males and females at Tipu varied in robusticity, the distribution of bone in the cross-section of all three elements does not differ. This suggests that while sexual dimorphism was present at Tipu, females were likely doing activities similar to those of males with regard to mobility and upper limb use.

This pattern of similarity in diaphyseal bone distribution among males and females is typical of farming communities (Ruff and Larsen, 1990) where females were engaged in just as many forms of physical labor as males. Lack of asymmetry in all CSG

properties for both males and females suggests the majority of everyday tasks required bi-manual work, which is also a common trend among agriculturalists (Larsen, 1995; 1997). Maya men traditionally hunted with bow and arrows, spears and blowguns (Tozzer, 1941; Redfield and Villa Rojas, 1964; Sharer, 1996). They were also responsible for the construction needs of their community (e.g. houses and communal spaces) and clearing land for, cultivating, weeding and harvesting milpas (Redfield and Villa Rojas, 1964). Women were responsible for getting water, gathering jungle resources, preparing food, maintaining house gardens, and making and washing clothes (Redfield and Villa Rojas, 1964; Sharer, 1996). While men were involved in frequent travel on foot to milpas, women were traveling on foot to gather jungle resources. Men utilized flint axes and blades to fell bush for milpas and carried heavy loads in the form of fire wood, harvested maize and construction materials, while women carried water, ground maize for flour with a mano and metate and washed clothes.

Tipu in Relation to Pre-contact Elites and Non-elites

Support for the hypothesis that the Tipu Maya more closely resemble pre-contact non-elites in skeletal robusticity was described in the previous section. This section provides a few more details pertaining to the question of how Colonial Period Maya activity patterns at Tipu related to those pre-contact elites and non-elites. When plotted together, non-elite males and females most often fall within the range of variation observed among Tipu burial groups, and elite males and females most often have the highest CSG means within that range. This indicates that patterns of better elite nutritional status and greater similarity between the activity patterns of the Tipu Maya and pre-contact non-elites persist, even when all comparative and Tipu burial groups are considered together (Appendix 3C). Also noteworthy is that Tipu females buried in the *atrio* remained the most gracile in tibial and humeral CSG of all other Maya females (Figure 4.8). This lends further support to the idea that at least a small number of females at Tipu had differential labor demands.

Homogeneity in the CSG properties of pre- and post-contact burial samples is also significant. The assumption that the activity patterns of the Tipu Maya did not change drastically over time, despite the new tribute systems and ways of life imposed by Spaniards (Graham, 2011), is supported by similar patterns of skeletal robusticity among the Maya buried at CBR and those buried in the context of the church at Tipu. This finding also highlights the importance of case by case studies when it comes to studying the effects of colonization events (Farriss, 1984; Gasco, 2005; Graham, 2011; Rogers, 2005). Whereas indigenous, agriculturally-based communities in North America experienced great lifestyle changes due to the increased labor demands that accompanied Spanish colonization (Larsen and Ruff, 1994; Larsen et al., 1996; 2001; Ruff and Larsen, 1990), Tipu represents an agricultural community where there were no discernible changes in activity patterns (Graham, 2011).

The relative homogeneity in CSG observed at Tipu indicates that some change in lifeways accompanied missionization. Nancy Farriss (1984) describes how the replacement of Maya authority figures by Spaniards made the former elites not so distinct from non-elites (Charlton and Nichols, 1992). In many cases, Maya communities were homogenized into a collection of farmers whose differences in status were not reflected by divisions of labor. Indicators of socioeconomic differentiation within such Maya communities are therefore not distinct because even if some individuals had specialized church-related duties, or served in public offices, every occupation was a part-time supplement to farming (Farriss, 1984). This may have also been the case at Tipu.

However, another important consideration is that Tipu was not a closed, completely isolated population. Maya from colonies in Northern Yucatan frequently fled the harsh conditions there for refuge in the frontier zone and some settled at Tipu (Farriss, 1984; Jones, 1998). Additionally, when the Itzá Maya took up colonization efforts of their own to keep Spaniards out of the Petén region, they relocated people from smaller surrounding communities to Tipu (Graham, 2011; Jones, 1998). Both of these events meant that Maya from other Lowland regions were likely added to the burial sample at Tipu, which may have contributed to the relative homogeneity observed in upper limb robusticity and mobility patterns.

In addition, we do not know how the Maya at Tipu may or may not have accommodated the social status of immigrants, or whether they perceived there to be enough room left in the nave for additional burials after a certain amount of time. To address this issue, a better understanding of the burial sequence at Tipu is needed. The burial sample there accumulated over a span of roughly 100 years, so it is possible that temporal changes occurred in where Tipuans interred people, and that later in Tipu's burial sequence social status had less to do with where individuals were placed in relation to the church. This is yet another factor that could have created the observed homogeneity in CSG of the upper and lower limb.

Conclusion

When the evidence for overall homogeneity in activity patterns at Tipu is considered with a pattern of sexual dimorphism that more closely resembles that of pre-contact non-elites and agriculturalists in general (Larsen, 1995; 1997; Ogilvie and Hilton, 2011; Ruff and Larsen, 1990), it is concluded that the Tipu burial sample likely represents a community of mostly rural farmers. There are a few differences in CSG among burial groups at Tipu that suggest some individuals of high status may have had more specialized activity patterns and did less manual labor, but there is also a large degree of overlap in the types and magnitude of both men's and women's activities regardless of status. These findings are typical of farming communities (Ruff and Larsen, 1990; Larsen, 1995; 1997), and not surprising given the everyday tasks of Maya men and women in farming communities (Redfield and Villa Rojas, 1964; Sharer, 1996).

This study of the Tipu burial sample provides an additional line of evidence supporting continuity in subsistence strategies at Tipu, as well as evidence for a reorganization of Maya social structure with missionization. This finding is best explained by the reduction of social distance between elites and non-elites that has been documented for the Maya elsewhere in the Lowlands (Charlton and Nichols, 1992; Farriss, 1984). However, the possible homogenizing effects of immigrants being added to

the burial sample, and possible temporal change in the use of particular burial locations, requires further investigation.

Chapter 5.

Conclusions

The historical, archaeological and bioarchaeological records of Tipu all indicate that it represents yet another unique outcome of Spanish colonization. Tipu also attests to the fact that the human biological effects of colonization were just as varied as the cultural outcomes (Larsen and Milner, 1994; White et al., 1994). The general trend of decline in health (Larsen and Milner, 1994) and increase in labor demands observed in the American Southwest (e.g. Chapman, 1997; Spielman, 2009) and Southeast (e.g. Larsen and Ruff, 1994; Larsen et al., 1996, 2001; Ruff and Larsen, 1990) did not occur at this frontier mission in Belize (Danforth et al., 1997; Jacobi, 2000; Cohen et al., 1994b). There was considerable continuity in subsistence strategies and tribute systems at Tipu (Emery, 1999; Graham, 1991; 2011; Graham et al., 1985; Jones, 1982) and therefore no evidence that missionization meant an intensification of labor to meet Spanish tribute demands, as it did elsewhere (Chapman, 1997; Larsen and Ruff, 1994; Spielman, 2009). Nevertheless, this dissertation provides bioarchaeological evidence that there were changes in Maya social structure at Tipu with missionization, and emphasizes the importance of a nuanced approach to the study of colonization.

Summary of Findings

This dissertation integrates two different methods for inferring past activity patterns from the human skeleton to determine whether changes in Maya social structure (inferred from distribution of labor) accompanied the Spanish missionization of Tipu. The methods are: a new 3D technique for quantifying the development of entheses; and the more widely used CSG of upper and lower limb long bones. The following is a summary of the conclusions made in Chapters 2-4 about the utility of the new 3D method for measuring entheses (Chapter 2), and about Tipu's Colonial Period social structure

(Chapters 3 and 4). In general, neither enthesis development nor long bone CSG of individuals from different burial groups at Tipu (inside and outside the church walls) conform to patterns observed among pre-contact Maya males and females of different social tiers. Therefore, the overarching conclusion is that there was a change in Maya social structure with the missionization of Tipu that involved reduction in social distance between community leaders and the rest of the population.

The two methods employed portray this finding in different ways. While their results seem contradictory, it is important to consider that each method measures different biomechanical influences on the skeleton. While some correlation between upper limb enthesis development and humeral CSG has been detected, the two indicators of habitual upper limb use do not correlate consistently across entheses for males or females (Niinimäki, 2012). This suggests that the forces applied to bone at each enthesis by its corresponding muscle action do not necessarily influence the cross-sectional shape of the long bone. This is likely because the shape of a long bone is more heavily influenced by forces of combined muscle contractions, not the action of a single muscle exerting force at a single point on the bone's cortex.

Another important consideration is that Tipu was not a closed, completely isolated population. Maya from colonies in Northern Yucatan frequently fled the harsh conditions there for refuge in the frontier zone (Farriss, 1984; Jones, 1998). The Itzá also relocated Maya from surrounding communities to Tipu when they took up colonization efforts of their own to keep Spaniards out of the Petén region (Graham, 2011; Jones, 1998). Both of these events meant that Maya from other Lowland locations were likely added to the burial sample at Tipu. We do not know how the Maya at Tipu may or may not have accommodated the social status of immigrants, or whether they perceived there to be enough room left in the nave for additional burials after a certain amount of time. To address this issue, a better understanding of the burial sequence at Tipu is needed. The burial sample there accumulated over a span of roughly 100 years, so it is possible that temporal changes occurred in where Tipuans interred people. For instance, later in Tipu's burial sequence, burial location in relation to the church may have had less to do with social status and more to do with where there was room for interments.

Chapter 2 Conclusions: A Test of the 3D Method for Measuring Enthesis Development

1) The 3D method for quantifying entheses development has relatively low intra-observer error rates.

The new method used in this study for quantifying (rather than qualitatively scoring) entheses development produced measurement error rates between 10% and 15%. These rates are relatively low and similar to those reported by other studies that categorize entheses on ordinal scales, or as either present or absent (Cardoso and Henderson, 2010; Villotte, 2006; Villotte et al., 2010). While inter-observer tests are needed, further use of 3D surface areas in the investigation of activity patterns with entheses development are warranted.

2) 3D surface areas and ordinal scores are similar representations of entheses development.

Further use of this method is also supported by agreement in the results of two seemingly disparate methods. Despite the expectation that 3D and ordinal methods for assessing entheses development would not agree in their results, because ordinal scores do not account for entheses size, this study suggests that 3D surface areas and ordinal scores are similar representations of entheses development. Both data sets agreed about which entheses are significantly asymmetrical and on which side the insertion is more pronounced. Considering the attributes of an entheses that ordinal scores and 3D surface areas represent, general agreement between the two methods is not necessarily surprising. When evaluating the morphology of an entheses and assigning a score, the observer is taking into account the rugosity, or roughness, of the insertion site, whether the area of rugosity is more or less distinct from normal cortex, and whether the insertion has pronounced bony crests (Hawkey and Merbs, 1995). Methods for visual inspection essentially take into account all the attributes of an entheses that a 3D representation of its surface area quantifies. In contrast, the 2D method does not produce similar results to

either the 3D or ordinal methods and enthesis size does not correlate consistently with surface areas. These findings likely reflect the fact that the 2D method only accounts for enthesis size and not surface topography (rugosity).

Chapter 3 Conclusions: Upper Limb Enthesis Development

1) Pre-contact elite and non-elite females differed in upper limb use, but pre-contact males did not.

Pre-contact female elites and non-elites differed in development of all seven entheses recorded. This suggests that females at opposite ends of the Maya social hierarchy differed in upper limb use, likely due to the agricultural activities that non-elite females engaged in. These activities included using a mano and metate for grinding corn, carrying water, maintaining house gardens, and making and washing clothes (Chapman, 1997; Redfield and Villa Rojas, 1964).

While male elites and non-elites differed in the development of some entheses, they were similar in the development of others. This suggests that there was overlap in the upper limb use of pre-contact male elites and non-elites. It is speculated that similarities observed are due to similar activity levels. The additional agricultural activities that non-elite males engaged in may account for the differences between the two social groups. Differential development of the brachialis, pectoralis major and biceps brachii between the two social tiers likely reflects the additional muscle actions required for non-elite males to fell bush with flint axes and machetes, plant crops and carry heavy burdens (like construction materials and harvested corn) (Chapman, 1997; Sharer, 1996).

2) Tipuans of presumably high and low status do not exhibit differences in upper limb use that replicate differences observed between pre-contact elites and non-elites.

This study did not detect differences among Tipu burial groups that indicate pre-contact social tiers persisted in the context of the *visita* mission. However, the

overarching prediction of this study that the Tipu burial sample represents a homogenous group of people with lifestyles most similar to those of a pre-contact, non-elite farming community is also not supported by the data presented here. There is no clear distinction in patterns of upper limb entheses development among Tipu burial groups that resembles that seen for pre-contact Maya samples. The differences observed between pre-contact elite and non-elite females were not seen among Tipu females. Similarly, males at Tipu did not exhibit the same pattern of similarity in some entheses and not others that was seen for pre-contact elite and non-elite males. The general picture that emerges is a complex one, in which the activity patterns of Tipu males and females were more diverse than expected.

3) Tipuans were not homogenous in habitual upper limb use. While the majority of individuals were likely full-time agriculturalists, there is evidence that some men and women did more specialized tasks.

A great deal of overlap was seen in upper limb use between Tipuans buried inside and outside the church walls. However, there is evidence for task specialization among both men and women of presumably higher status at Tipu. Overlap in activity patterns, with only a few instances of task specialization, suggests that there was a different type of social stratification at Tipu where the lifestyles of high and low status people were not as clear cut as they were in the Classic/Postclassic. Since male elites and non-elites were not easily distinguishable based on entheses development, it is likely that the activity patterns of both pre-contact and Colonial Period males of high and low status also overlapped. Elite and non-elite males did similar activities involving the upper limb, as did males of high and low status (represented by burial location) at Tipu. At the same time, there is some evidence that males buried inside the church, and females buried in the *atrio*, engaged in more specialized tasks. This suggests there was a social hierarchy in effect at Tipu that does not necessarily mimic that of a strictly agricultural Maya community where both manual labor and public service are communal positions, and everyone is primarily engaged in agricultural tasks (Redfield and Villa Rojas, 1964). This diversity of

enthesis development could also be influenced by the inclusion of immigrants from distant Lowland regions, who had different subsistence strategies, in the Tipu burial sample. A better understanding of which Lowland regions individuals at Tipu represent, as well as clarification of the site's burial sequence over time, are required before this possible evidence for task specialization and its relation to social status at Tipu can be investigated further.

Chapter 4 Conclusions: CSG of the Humerus, Femur and Tibia

1) Pre-contact non-elite females were more mobile than elite females, while the activity and mobility patterns of elite and non-elite males were more similar.

Non-elite females exhibited more AP expansion of the tibiae that actually resembled that of non-elite males, while elite females had more eurycnemic tibial shapes. This is indicative of more frequent walking among non-elites, and is consistent with the task of gathering jungle resources that was common among non-elite Maya women (Redfield and Villa Rojas, 1964; Sharer, 1996). Since the femora of non-elite females did not exhibit similar AP expansion, they were not running or traversing rugged terrain (Ruff, 1987). This also indicates that the females interred at Caves Branch Rockshelter generally restricted their travel to the less rugged terrain of river valleys.

No differences in cross-sectional properties of the humerus, femur or tibia were observed between pre-contact elite and non-elite males. While they may have performed different activities this was not detected in skeletal robusticity or the cross-sectional shape of long bones. This likely indicates that the activity *levels* of pre-contact elite and non-elite males were not that different. Non-elites engaged in manual labor associated with the construction needs of a community, planting and harvesting milpas, and hunting and gathering in surrounding jungle and river ecosystems (Redfield and Villa Rojas, 1964; Sharer, 1996). Elite males may have participated in hunting activities of their own (Jones, 1998) and likely did a similar amount of physical activity. Physical training was required for warfare and the ball game. Maya elites also traveled between major centers

on foot or via watercraft (Jones, 1998). The combination of such training and mobility patterns may explain the similarity in elite and non-elite males observed here.

2) Tipuans were generally homogenous in activity patterns, but a few notable exceptions are suggestive of a society where a few individuals of higher status engaged in more specialized activities.

The majority of burial groups at Tipu were generally homogenous in cross-sectional properties of the humerus, femur and tibia. However, notable exceptions were observed for both males and females. Females buried in the *atrio*, to the north of the church were more gracile than all other females at Tipu. They were not less mobile than other females, but they likely did less manual labor. Perhaps the *atrio* represents a high status burial location. A few males buried inside the church were also more gracile than other Tipu males. This suggests that some men and women were not full-time agriculturalists like the majority of the community. They may have done more specialized activities that were associated with high status. For instance, in the Colonial Period, it was common for Maya men to become *maestros cantores* by attending Franciscan schools, so that they could teach Christianity and carry out services and rituals while friars were absent (Farriss, 1984; Graham, 2011). While *maestros cantores* are also equally involved in agricultural tasks in contemporary populations (Redfield and Villa Rojas, 1964), it seems likely that there could have been Maya priests with reduced agricultural duties at Tipu considering that Spanish friars were often absent.

3) The majority of both males and females at Tipu were engaged in labor associated with agriculture. Their activity patterns are more similar to that of pre-contact non-elites. Also, while sexual dimorphism existed in body size, males and females at Tipu were very similar in the cross-sectional shapes of long bones, indicating that while sexual divisions of labor existed, males and females were doing similar amounts of work.

The overall homogeneity in cross-sectional properties of the humerus, femur and tibia among Tipu males and females, (regardless of burial placement) and their greater similarity to pre-contact non-elites, suggests Colonial Period Tipu was primarily an agricultural community. There was a great deal of overlap in the activity patterns of high and low status individuals, because the majority of high status individuals still had to do their own farming (Farriss, 1984; Redfield and Villa Rojas, 1964). This is common among contemporary Maya groups as well (Redfield and Villa Rojas, 1964). Men are required to serve in public offices, but only for a few weeks. Then the next group of public officers are appointed (Redfield and Villa Rojas, 1964). Regardless of these appointments, men are still engaged in agricultural activities. As mentioned, even *maestros cantores* are still responsible for their own milpas (Redfield and Villa Rojas, 1964).

Tipu males and females also demonstrate a pattern of sexual dimorphism in CSG properties that is typical of agricultural communities (Ruff and Larsen, 1990). Sexual dimorphism in the torsional and bending strength of the humerus, femur, and tibia is significant, but the cross-sectional *shapes* of these elements did not differ significantly between males and females. This similarity in shape suggests that females at Tipu were likely doing activities similar to those of males with regard to mobility and upper limb use. Maya men traditionally hunted with bows and arrows, spears and blowguns (Tozzer, 1941; Redfield and Villa Rojas, 1964; Sharer, 1996). They were also responsible for the construction needs of their community (e.g. houses and communal spaces) and clearing land for crops, cultivating, weeding and harvesting milpas (Redfield and Villa Rojas, 1964). Women were responsible for getting water, gathering jungle resources, preparing food, maintaining house gardens, and making and washing clothes (Redfield and Villa Rojas, 1964; Sharer, 1996). While men were involved in frequent travel on foot to milpas, women were traveling on foot to gather jungle resources. Men utilized flint axes and blades to fell bush for milpas and carried heavy loads in the form of fire wood, harvested maize and construction materials, while women carried water, ground maize for flour with a mano and metate, maintained house gardens and washed clothes.

Conclusions Regarding the Central Research Question: Was the Spanish missionization of Tipu accompanied by change in Maya social structure?

Both studies of entheses development and CSG presented in this dissertation agree that Maya social structure, as it can be observed from the distribution of labor at Tipu, changed with Spanish missionization. While there may have been some task specialization, the lifestyles of presumably high and low status individuals were not as different as they had been in pre-contact times. This finding is likely reminiscent of the "collapse" of the Maya social hierarchy that occurred elsewhere in the Lowlands when Spaniards replaced elites at the top of the social pyramid (Charlton and Nichols, 1992). In this case, collapse refers to the reduction in social distance between elite and non-elite groups.

Nancy Farriss (1984) describes how the replacement of Maya authority figures by Spaniards made the former elites not so distinct from non-elites (Charlton and Nichols, 1992). In many cases, Maya communities were homogenized into a collection of farmers whose differences in status were not reflected by divisions of labor. Indicators of socioeconomic differentiation within such Maya communities are therefore not distinct because even if some individuals had specialized church-related duties, or served in public offices, every occupation was a part-time supplement to farming (Farriss, 1984). This is a pattern that has continued in contemporary Maya communities (Redfield and Villa Rojas, 1964).

The greatest contradiction between the results of the entheses study and the CSG study is in the degree of homogeneity in inferred activity patterns among burial groups at Tipu. CSG produced a picture of general homogeneity in activity patterns between high and low status burials, for both the upper and lower limb. Patterns of entheses development between inside and outside burial groups did suggest some overlap in activity patterns, but ultimately portrayed a less homogenous view of habitual muscle use. This is likely because the two methods measure different types of biomechanical effects on the skeleton. Another possibility is that diversity in upper limb entheses development reflects the inclusion of immigrants with different activity patterns in the Tipu burial sample.

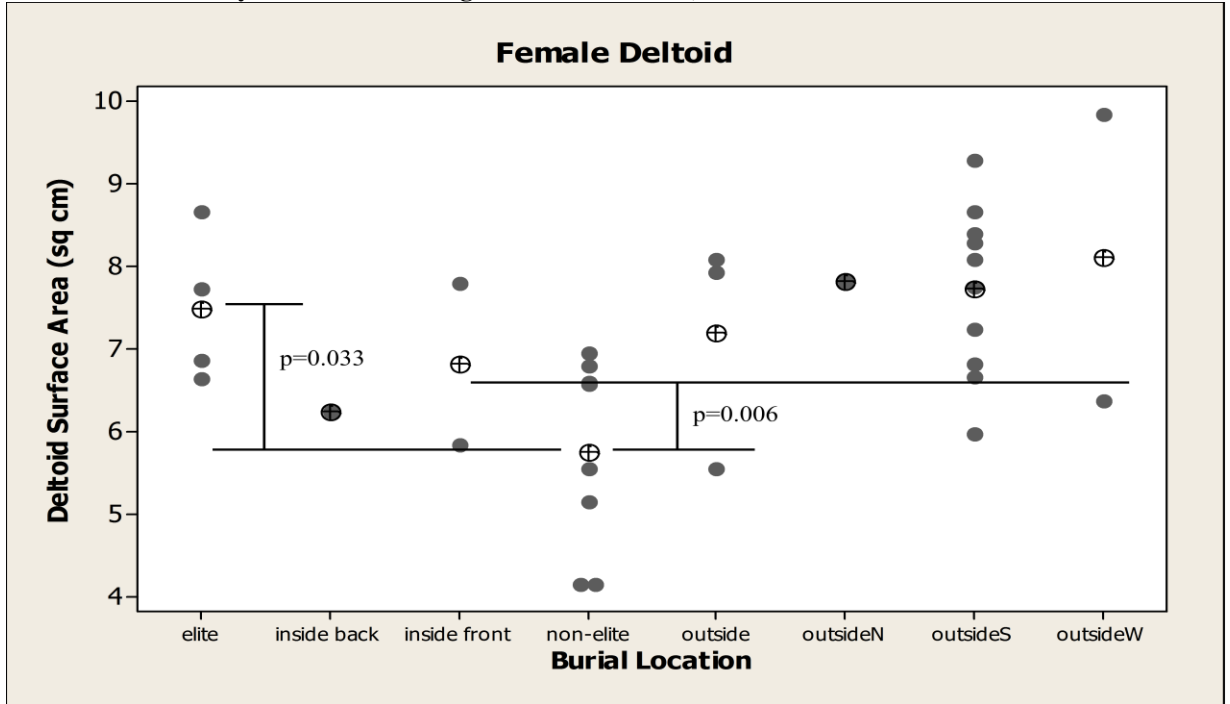
Nevertheless, the two studies did point out similar exceptions to homogeneity in activity patterns for both males and females. Females buried in the *atrio* had greater development of the pronator teres along with more gracile long bones. Males buried inside the church demonstrated less development of the pectoralis major and supinator along with more gracile humeri. This suggests that a few individuals of higher status did not engage in as much manual labor as other Tipuans. Some high status females may have devoted more time to craft manufacture (e.g. weaving), and some high status males may have held more full-time positions as community or religious leaders.

It seems that the relative homogeneity in CSG properties among burial groups at Tipu, the overlap in development of some entheses but not others, and the very different patterns of bone functional adaptations observed between pre-contact and Colonial Period samples are best explained by the reduction of the gap between elites and non-elites that has been documented for the Maya elsewhere in the Lowlands (Farriss, 1984). Future research that will contribute significantly to our knowledge of Tipu includes determining the relative temporal sequence of interments at the site, and the regional origins of individuals. This would address whether the homogeneity observed in CSG of the upper and lower limb among burial groups does actually reflect homogeneity in activity patterns and reduction in social distance, or whether mass immigrations and/or temporal change in how burial locations were chosen had homogenizing effects on the Tipu burial sample. These types of future research would also greatly contribute to the proposed evidence for task specialization at Tipu. They would clarify whether a greater diversity of entheses development is actually due to a greater variety of activity patterns and task specializations among certain segments of society, or whether the interment of immigrants with different subsistence strategies in various burial locations had a greater effect on observed patterns.

Appendices

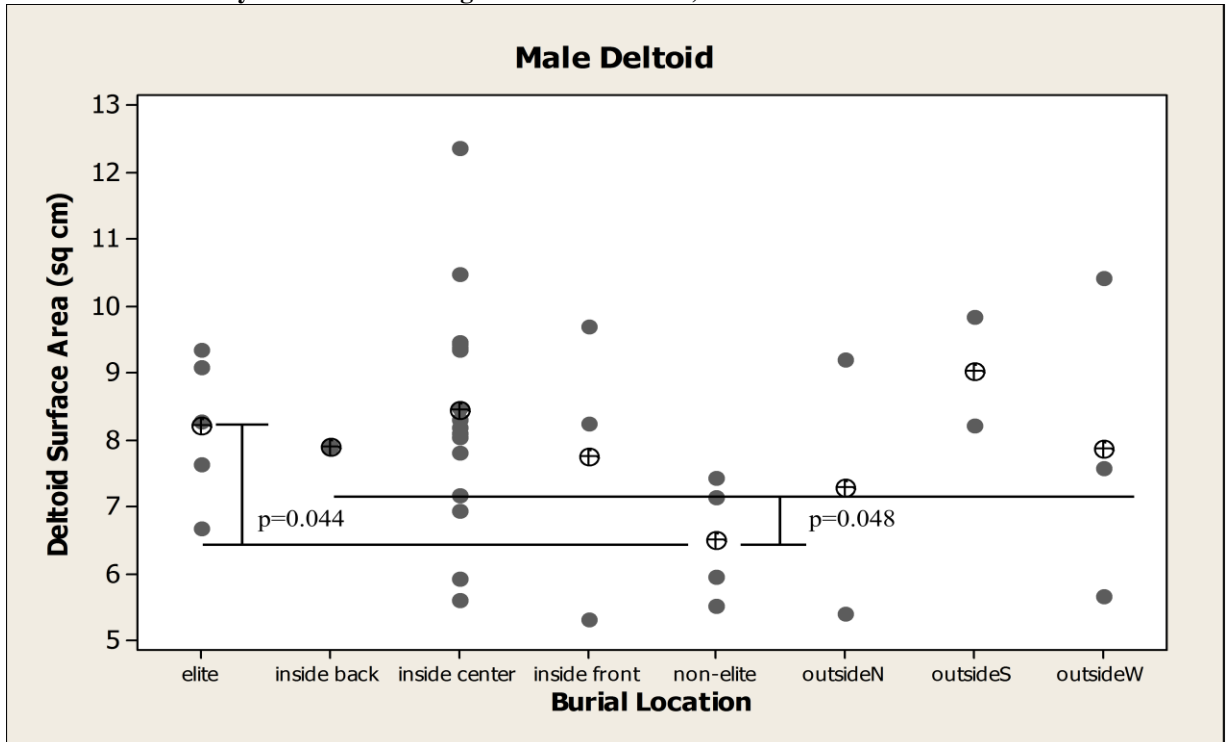
Appendix 1: Individual Value Plots and Significant Mann-Whitney U tests

Individual Value Plot of Deltoid Surface Areas: Females (lines and p-values indicate comparisons for which Mann-Whitney U tests detected significant differences)



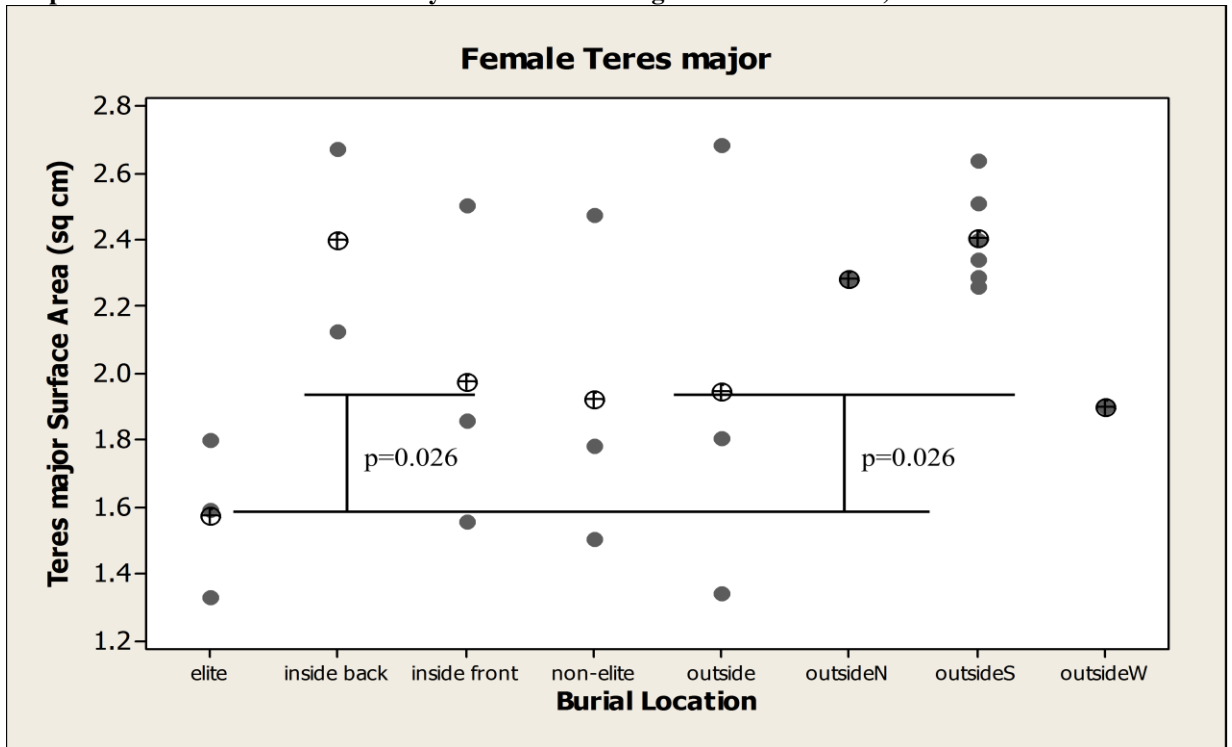
*circles with cross-hairs indicate mean values

Individual Value Plot of Deltoid Surface Areas: Males (lines and p-values indicate comparisons for which Mann-Whitney U tests detected significant differences)



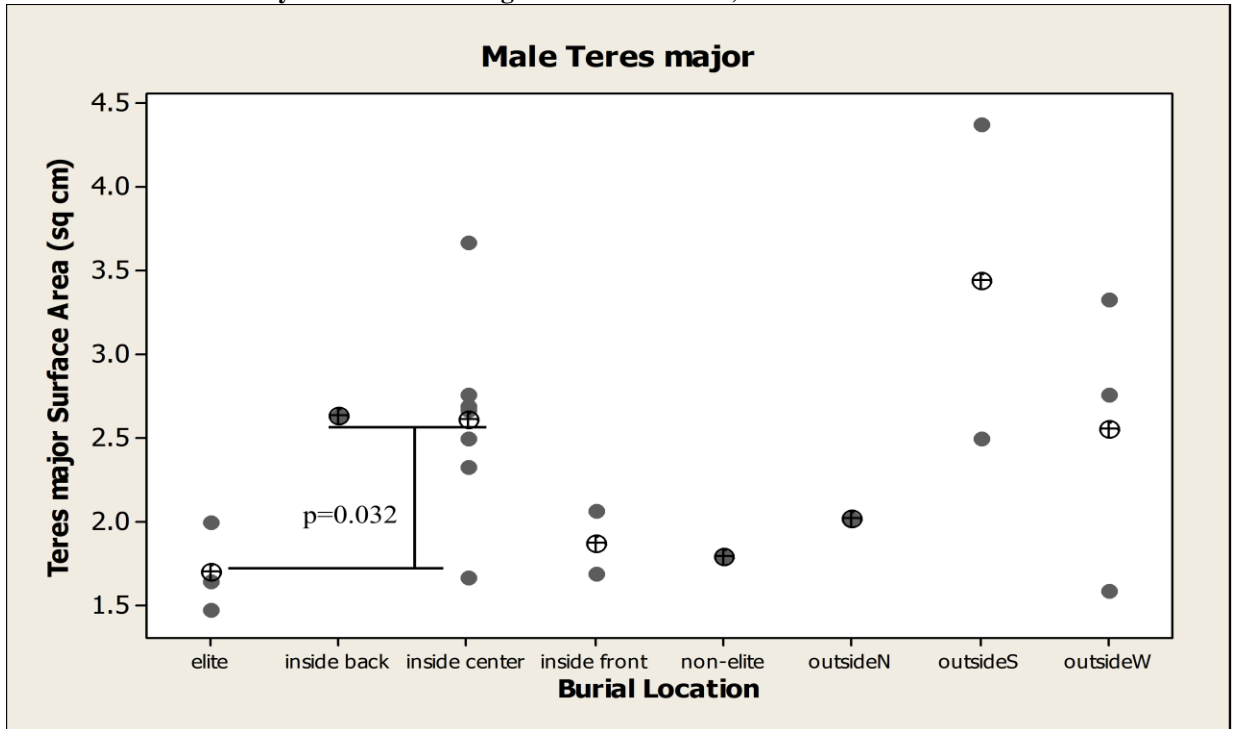
*circles with cross-hairs indicate mean values

Individual Value Plot of Teres major Surface Areas: Females (lines and p-values indicate comparisons for which Mann-Whitney U tests detected significant differences)



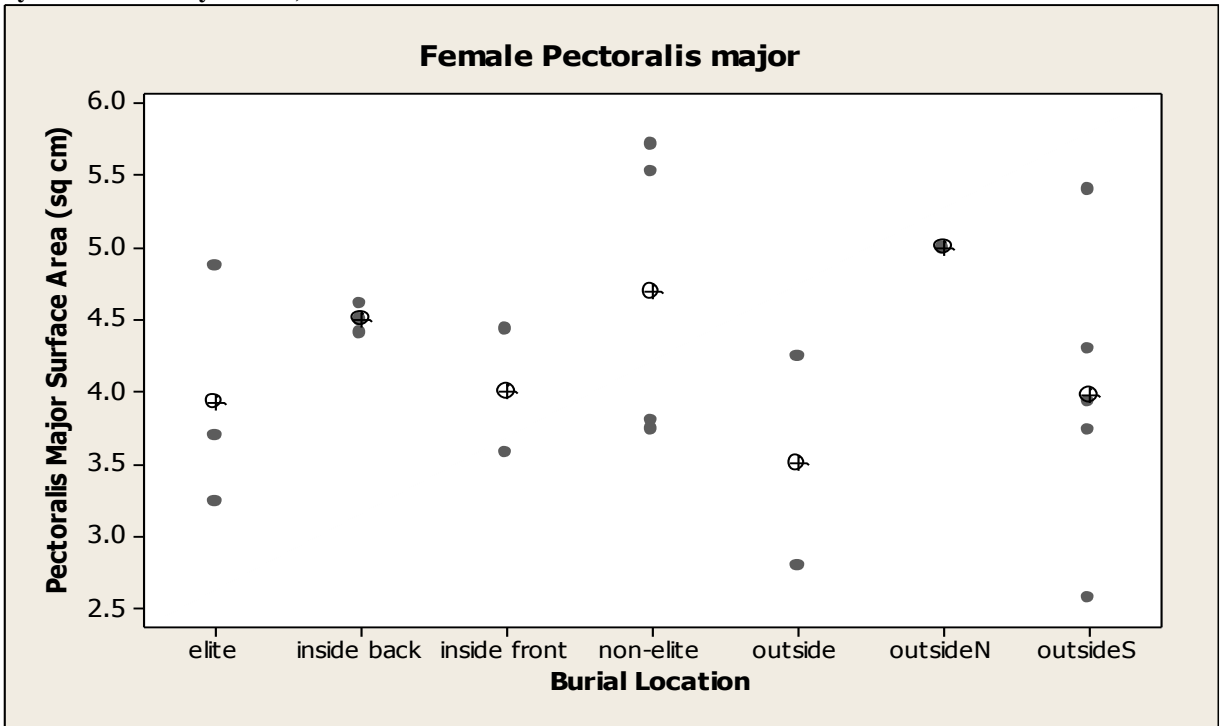
*circles with cross-hairs indicate mean values

Individual Value Plot of Teres major Surface Areas: Males (lines and p-values indicate comparisons for which Mann-Whitney U tests detected significant differences)



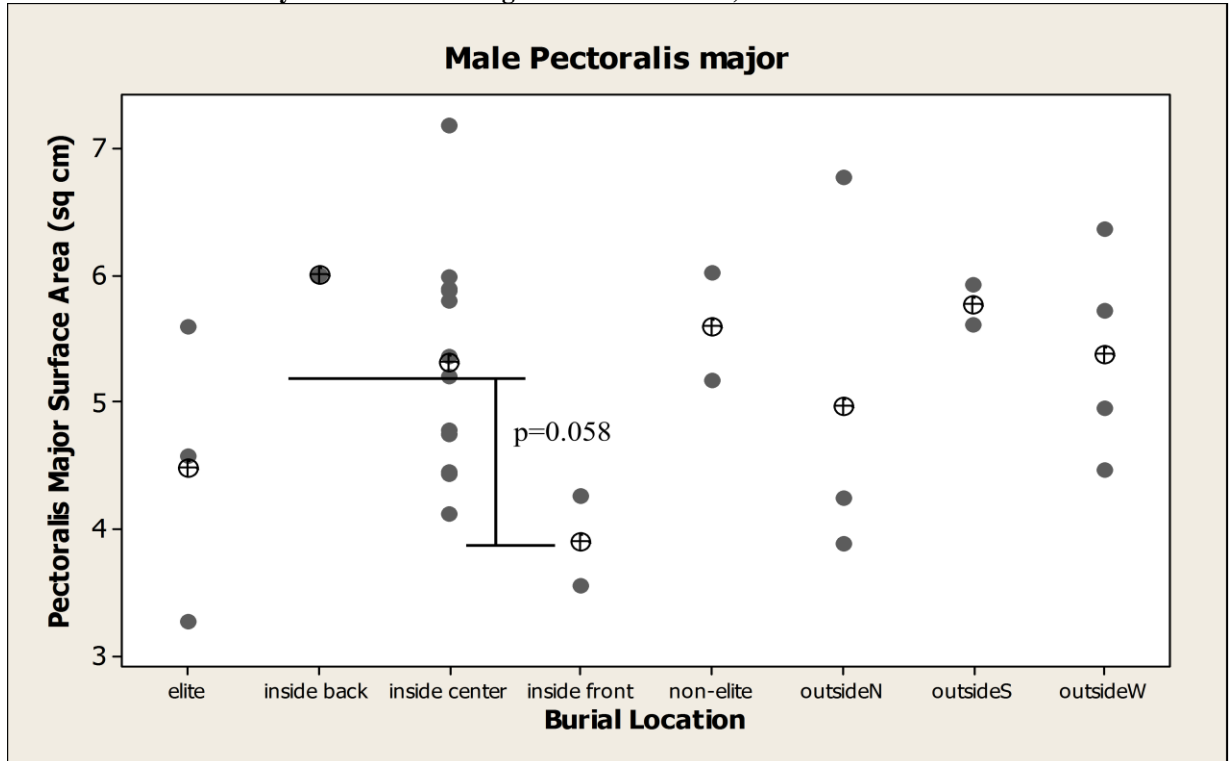
*circles with cross-hairs indicate mean values

Individual Value Plot of Pectoralis major Surface Areas: Females (no significant differences detected by Mann-Whitney U tests)



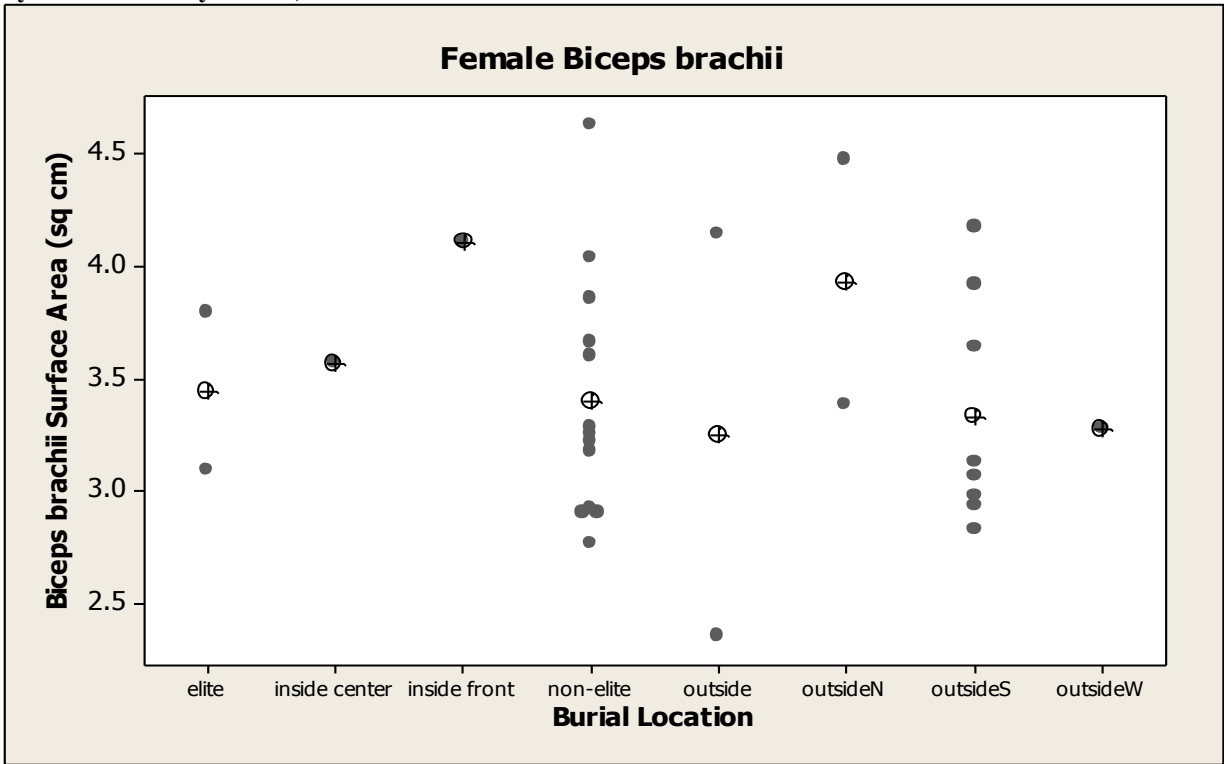
*circles with cross-hairs indicate mean values

Individual Value Plot of Teres major Surface Areas: Males (lines and p-values indicate comparisons for which Mann-Whitney U tests detected significant differences)

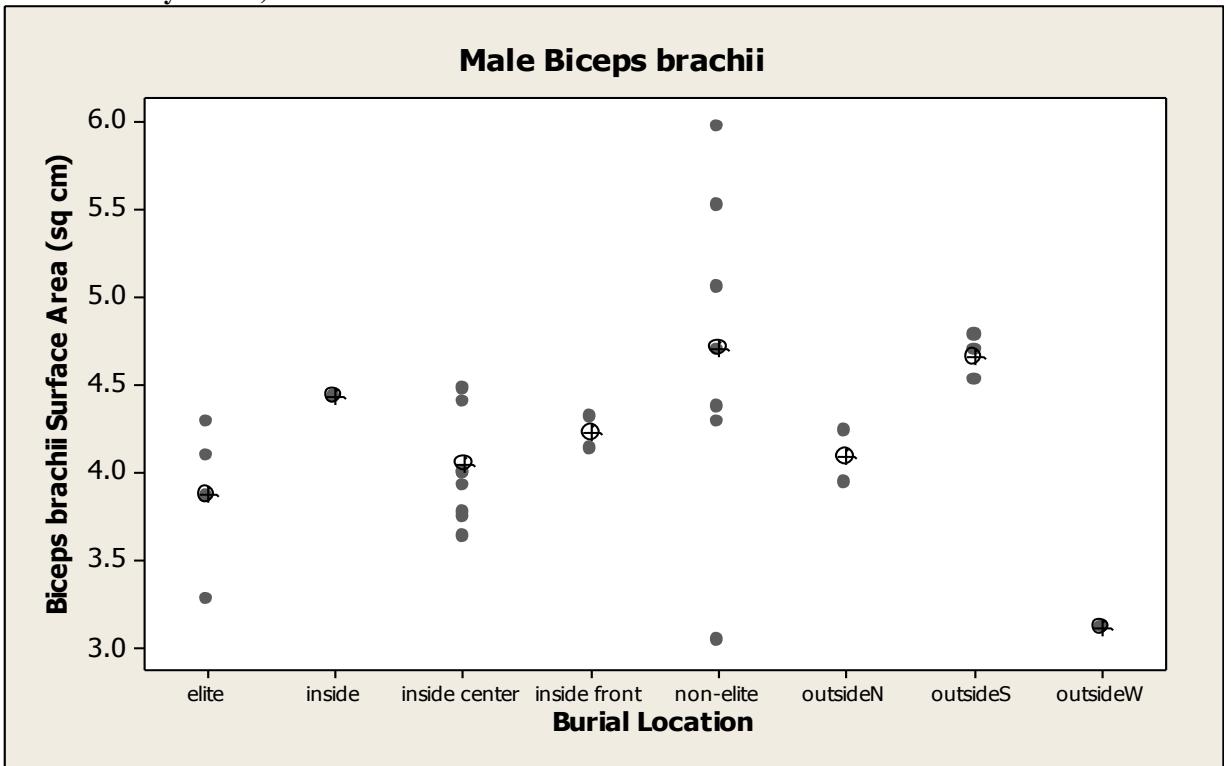


*circles with cross-hairs indicate mean values

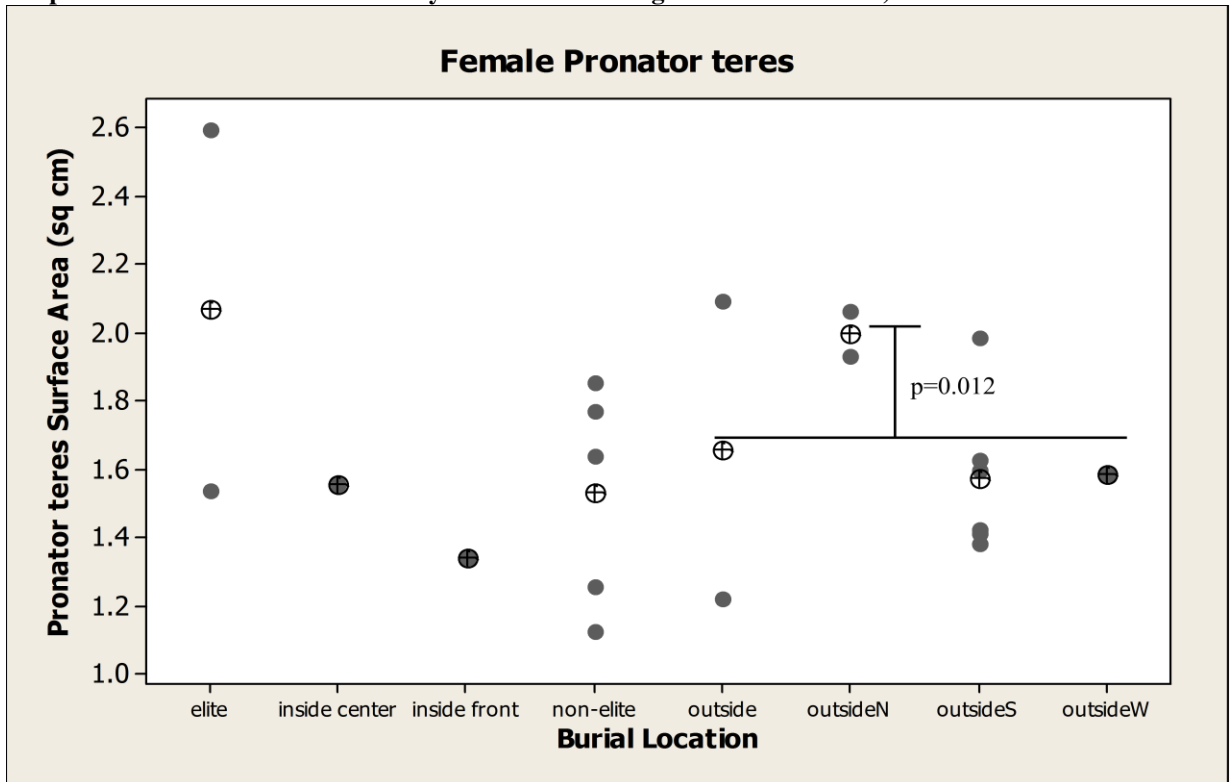
Individual Value Plot of Biceps brachii Surface Areas: Females (no significant differences detected by Mann-Whitney U tests)



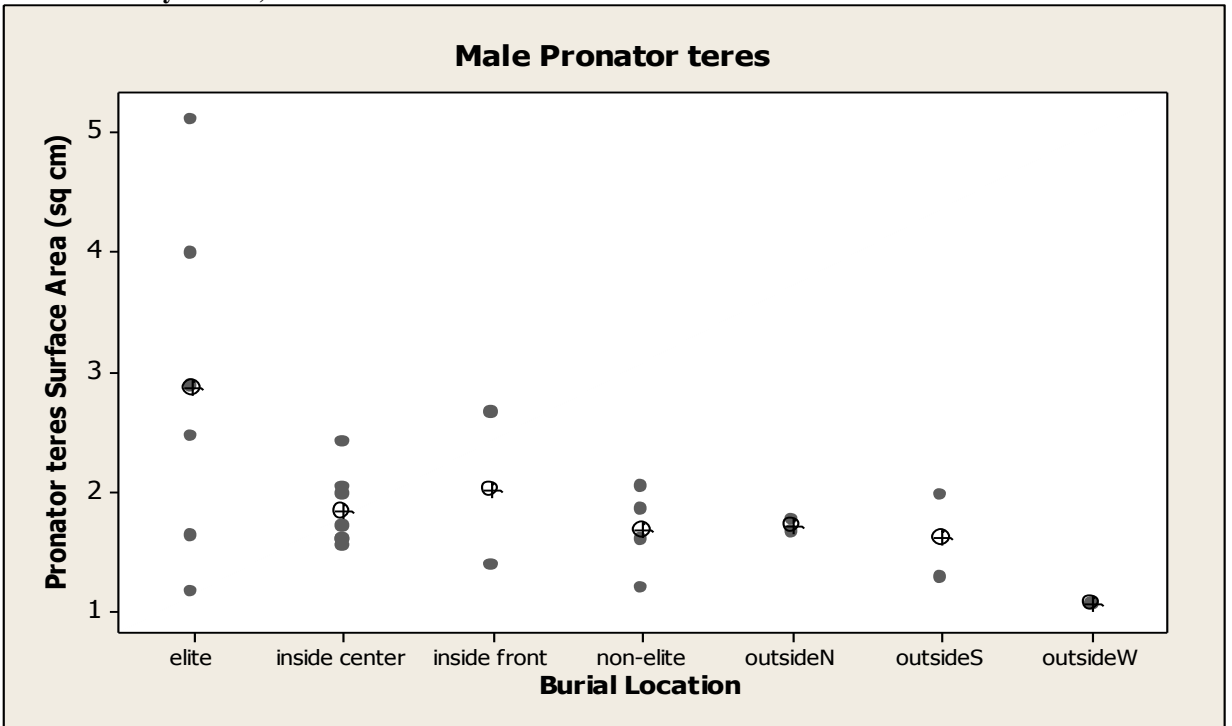
Individual Value Plot of Biceps brachii Surface Areas: Males (no significant differences detected by Mann-Whitney U tests)



Individual Value Plot of Teres major Surface Areas: Females (lines and p-values indicate comparisons for which Mann-Whitney U tests detected significant differences)

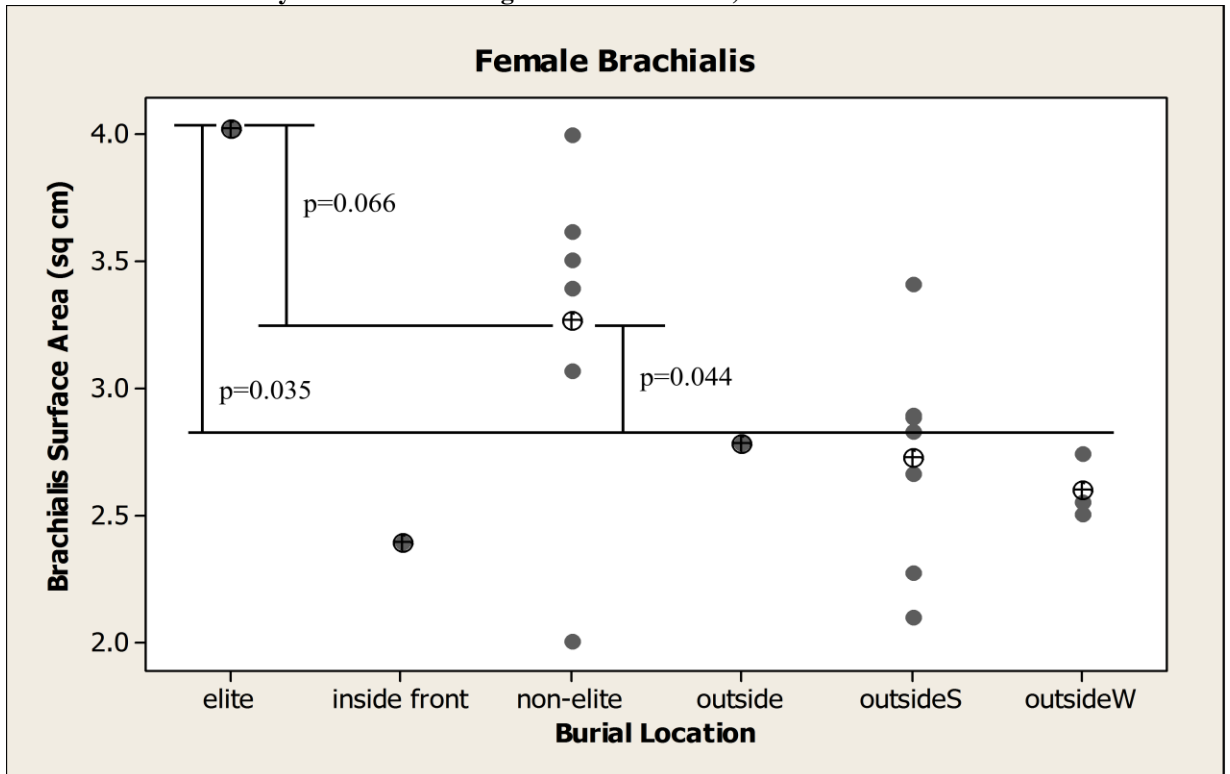


Individual Value Plot of Pronator teres Surface Areas: Males (no significant differences detected by Mann-Whitney U tests)

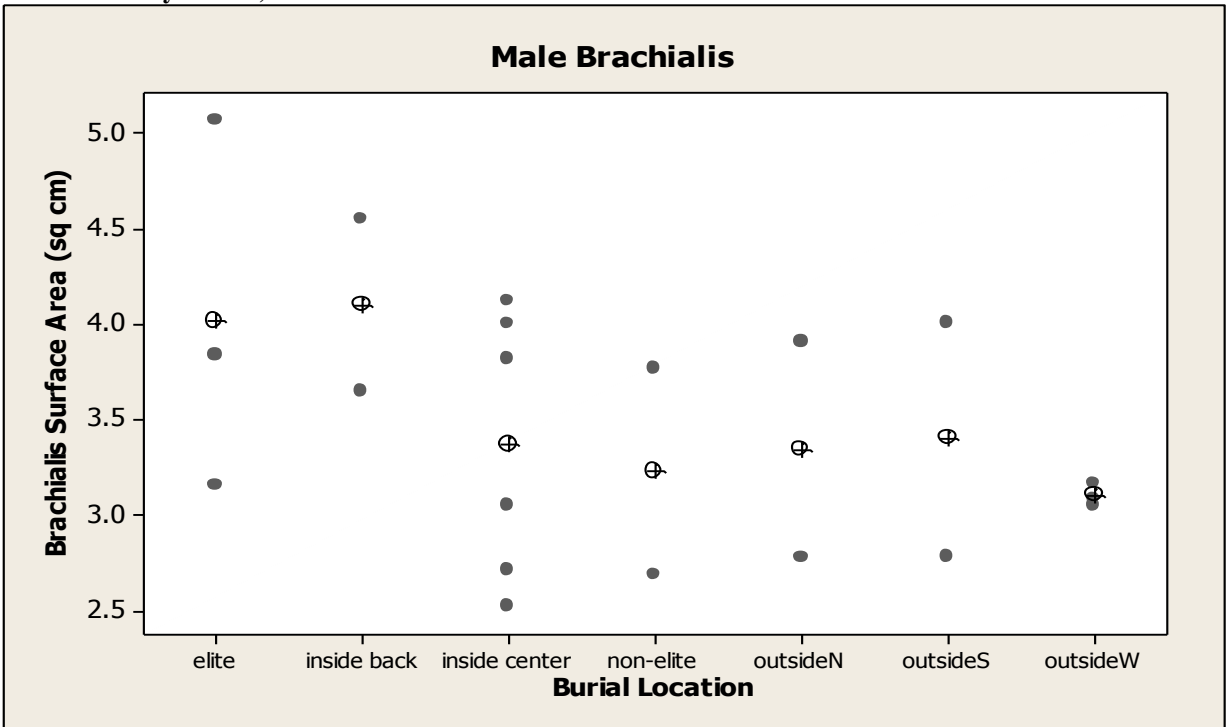


*circles with cross-hairs indicate mean values

Individual Value Plot of Brachialis Surface Areas: Females (lines and p-values indicate comparisons for which Mann-Whitney U tests detected significant differences)

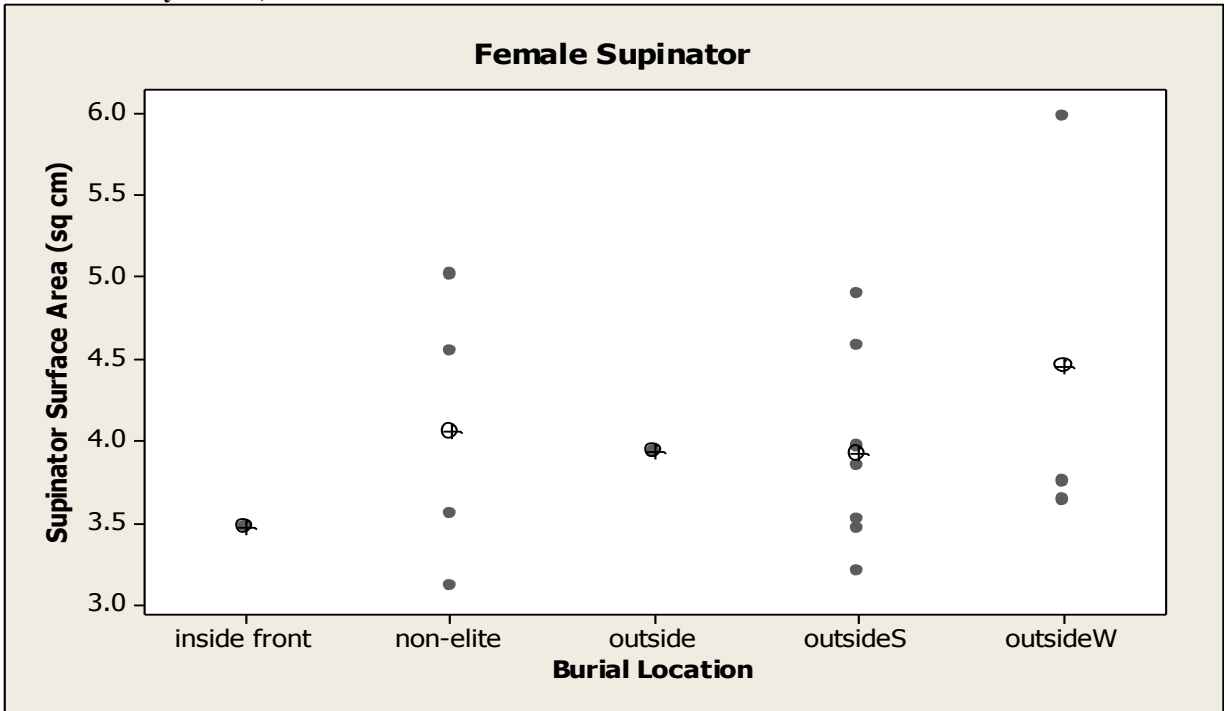


Individual Value Plot of Brachialis Surface Areas: Males (no significant differences detected by Mann-Whitney U tests)



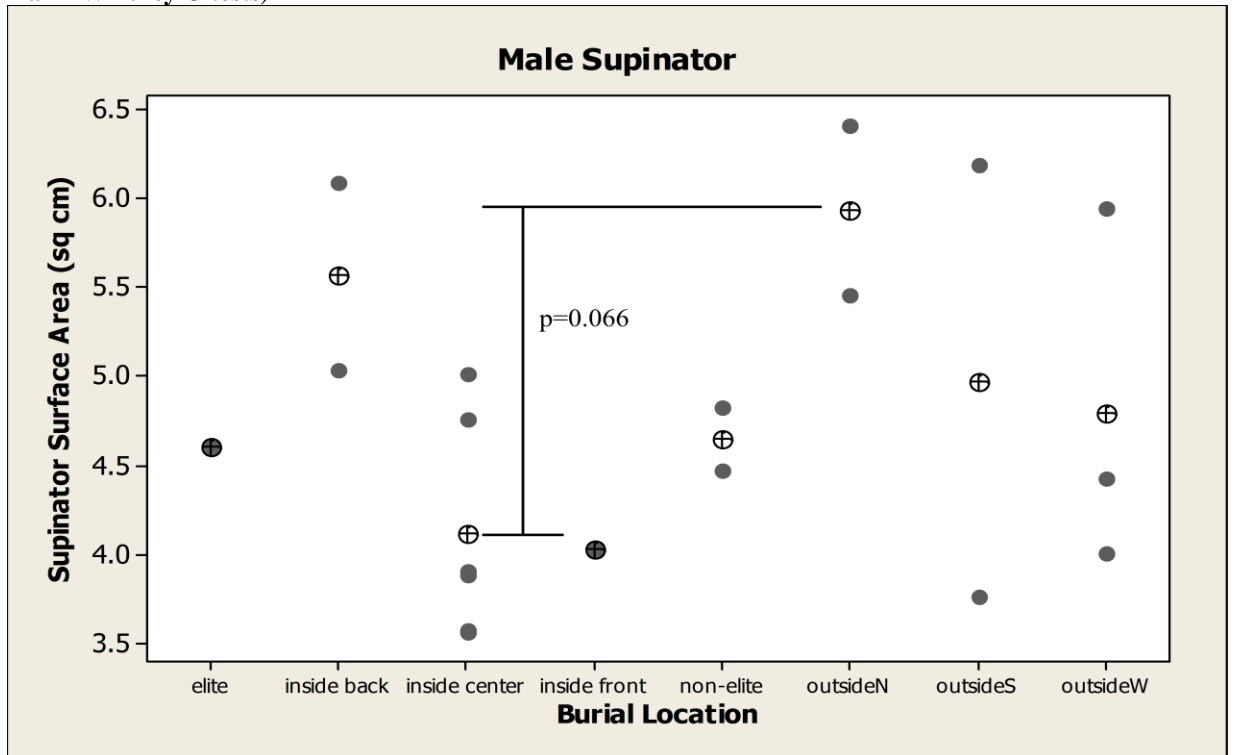
*circles with cross-hairs indicate mean values

Individual Value Plot of Supinator Surface Areas: Females (no significant differences detected by Mann-Whitney U tests)



*circles with cross-hairs indicate mean values

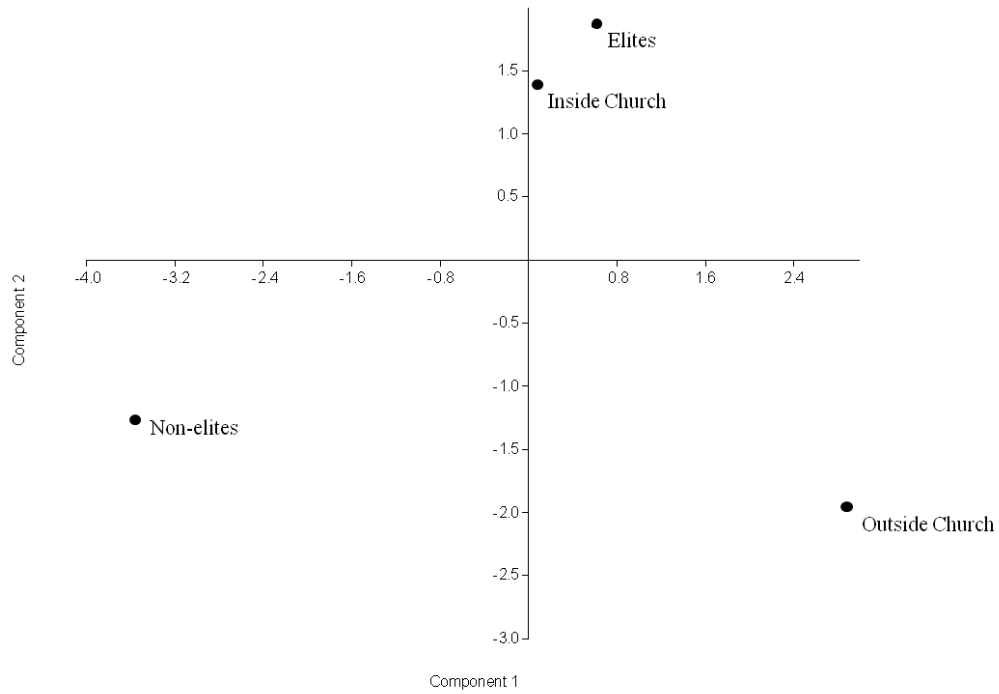
Individual Value Plot of Supinator Surface Areas: Males (no significant differences detected by Mann-Whitney U tests)



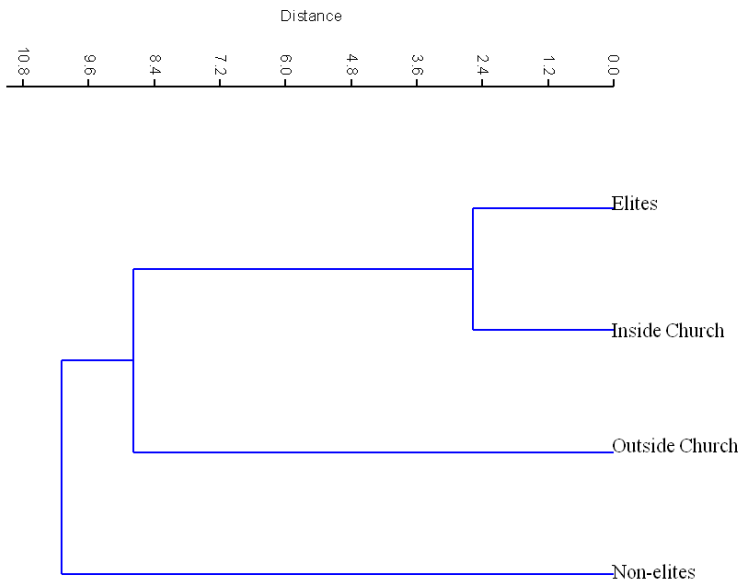
*circles with cross-hairs indicate mean values

Appendix 2: PCA and Cluster Analyses

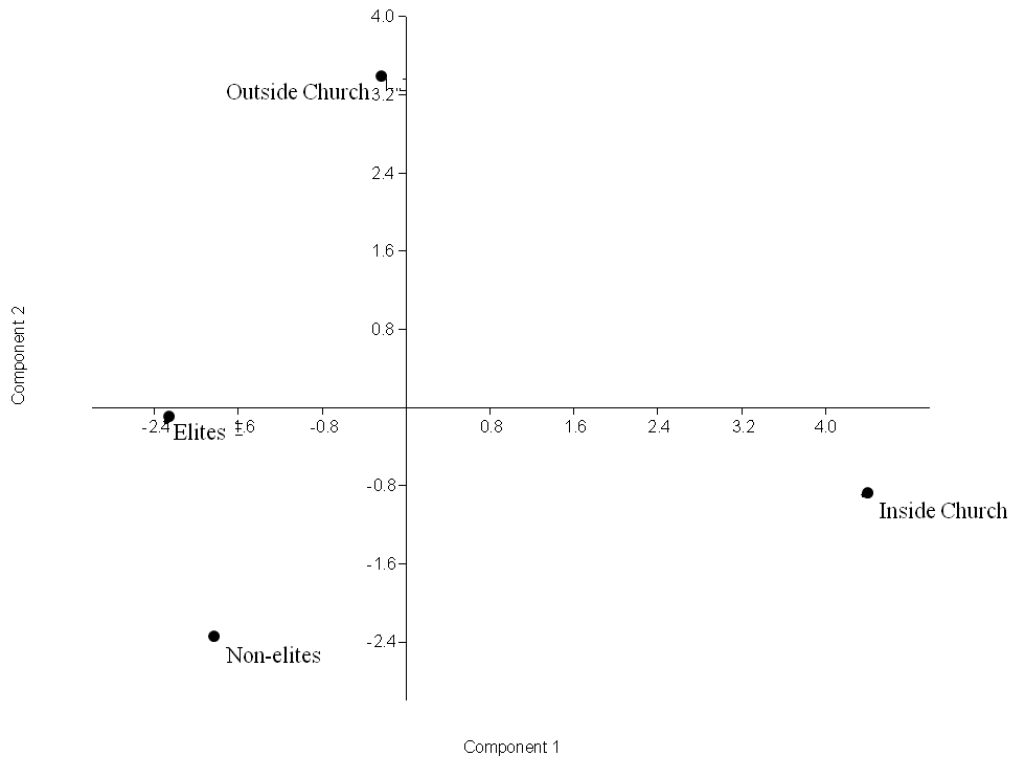
PCA and Cluster - Deltoid Surface Areas: Females



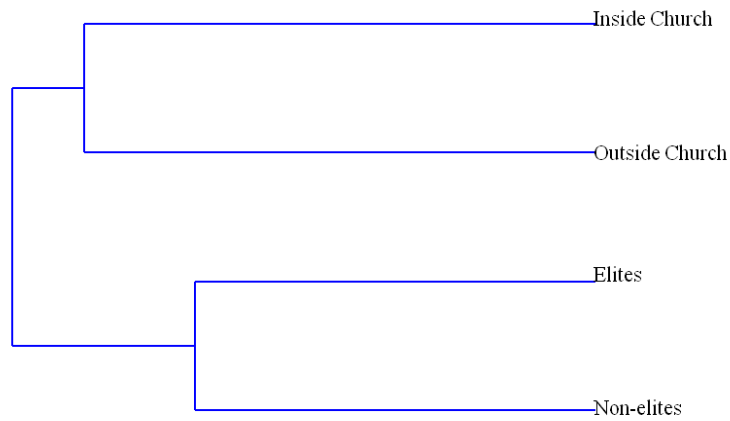
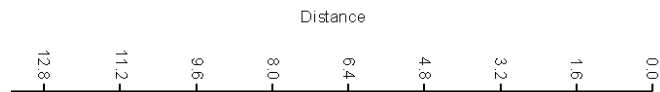
PC	Eigenvalue	% variance
1	7.09954	63.253
2	3.66127	32.62
3	0.463259	4.1274



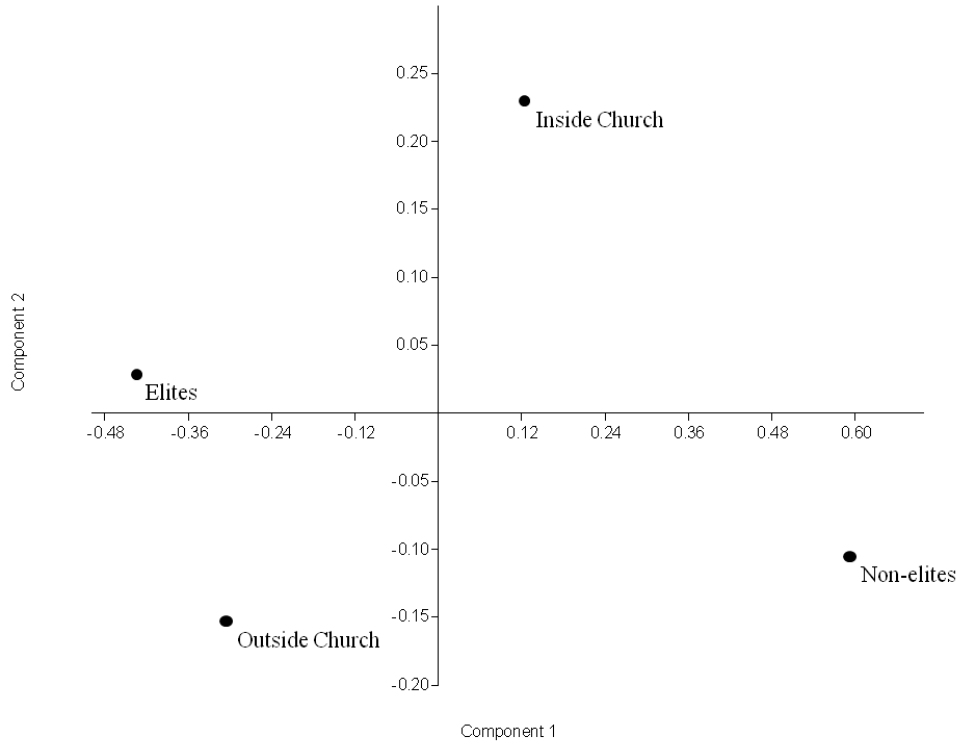
PCA and Cluster - Deltoid Surface Areas: Males



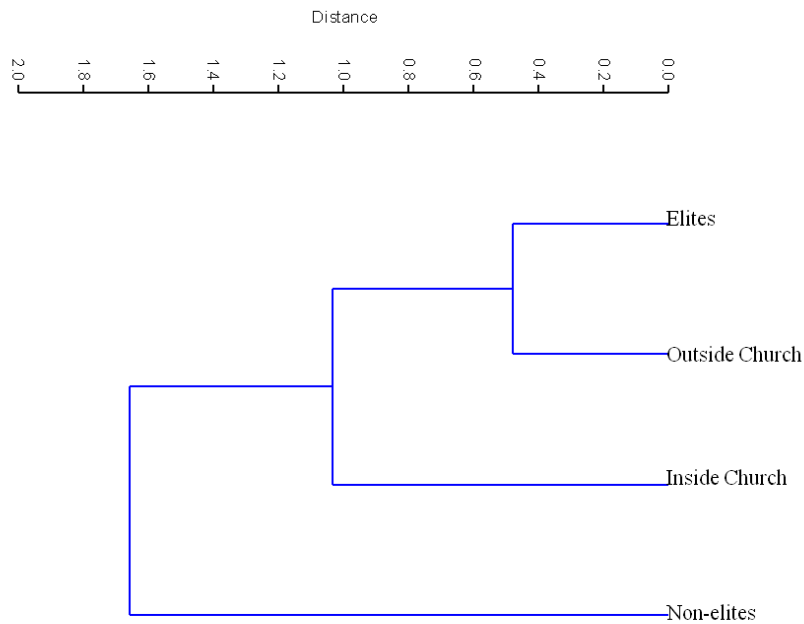
PC	Eigenvalue	% variance
1	9.27082	54.657
2	5.90315	34.803
3	1.78782	10.54



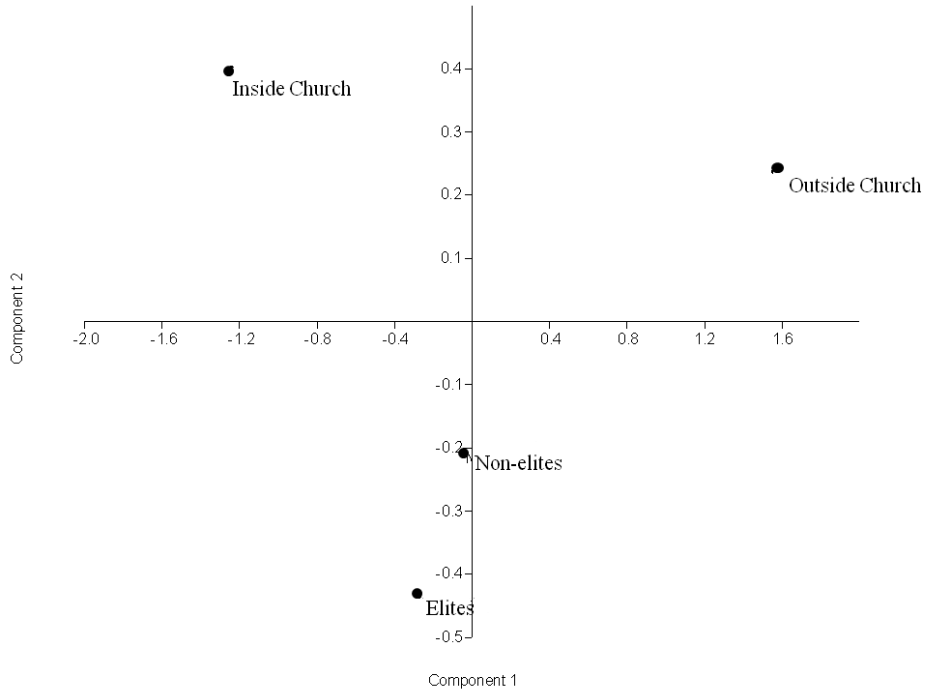
PCA and Cluster - Teres major Surface Areas: Females



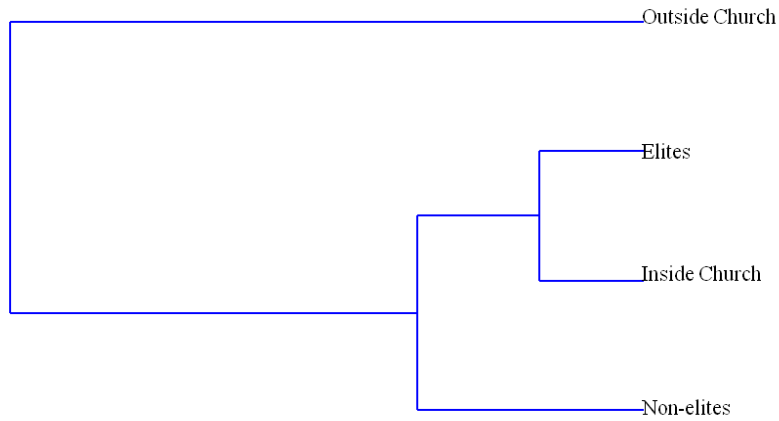
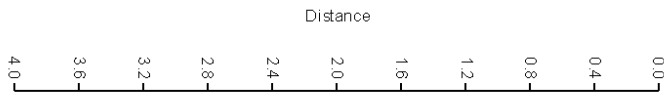
PC	Eigenvalue	% variance
1	0.217964	84.156
2	0.029202	11.275
3	0.0118349	4.5694



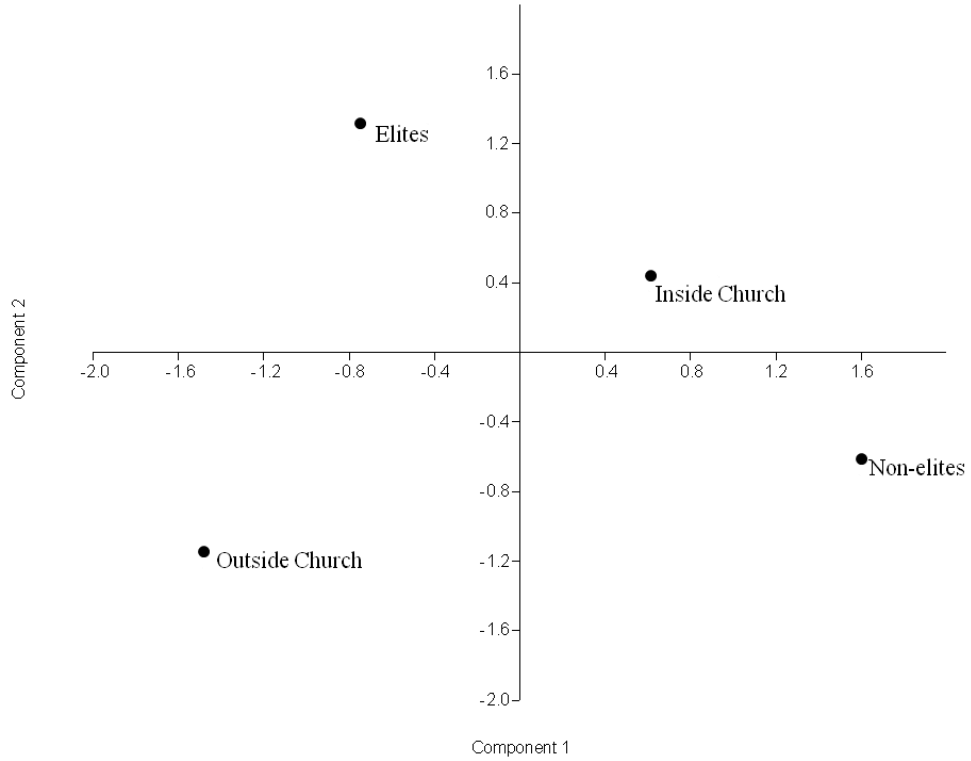
PCA and Cluster - Teres major Surface Areas: Males



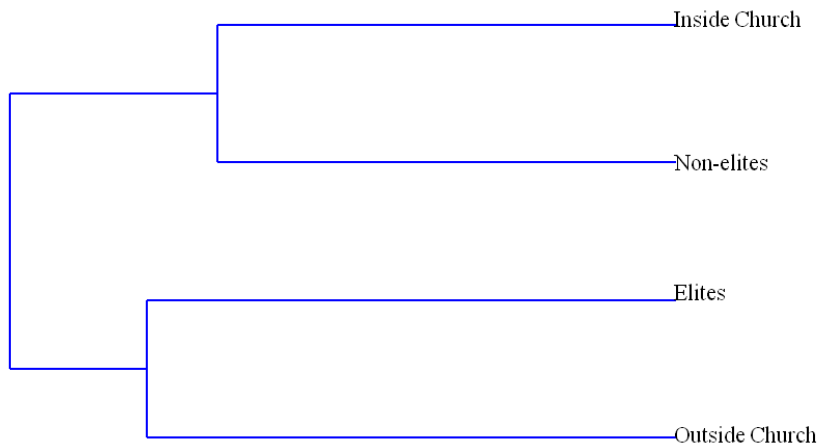
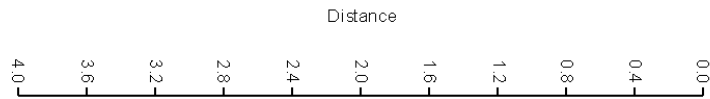
PC	Eigenvalue	% variance
1	1.34861	89.591
2	0.149134	9.9073
3	0.00755	0.50156



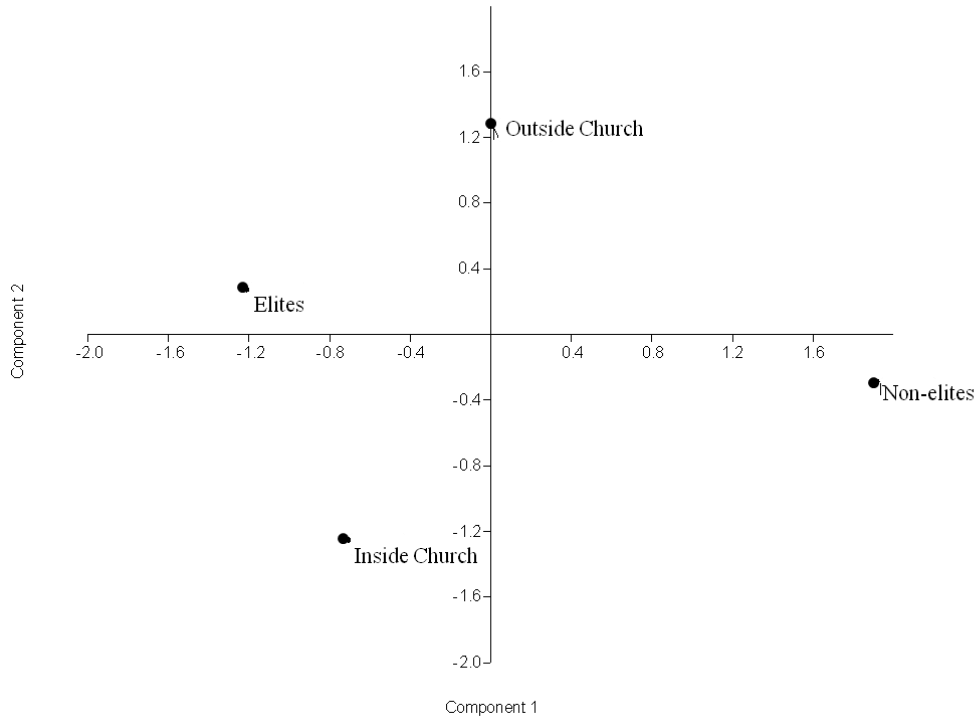
PCA and Cluster - Pectoralis major Surface Areas: Females



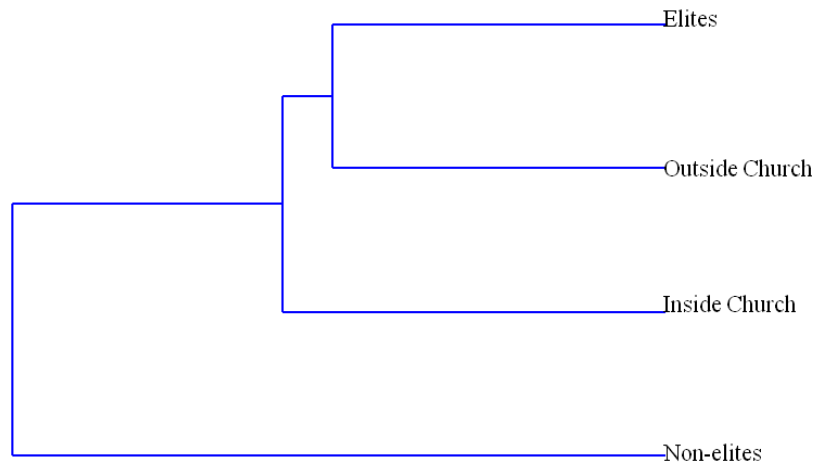
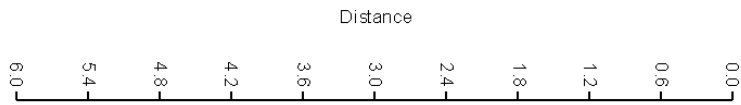
PC	Eigenvalue	% variance
1	1.91112	53.198
2	1.20138	33.442
3	0.479953	13.36



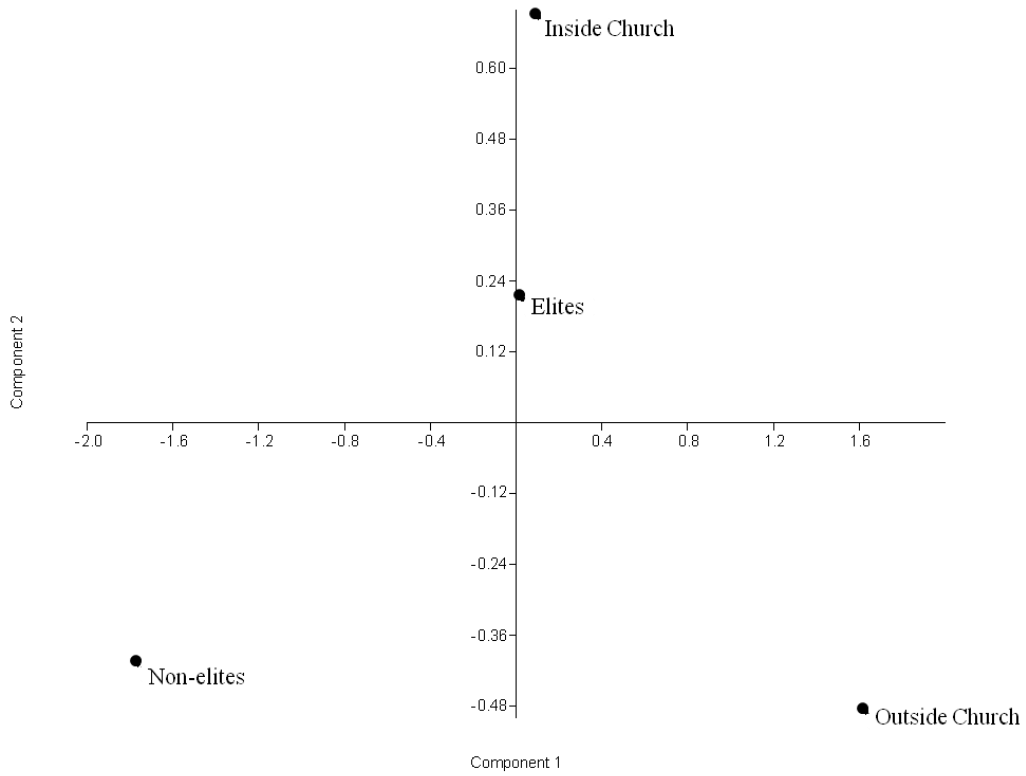
PCA and Cluster - Pectoralis major Surface Areas: Males



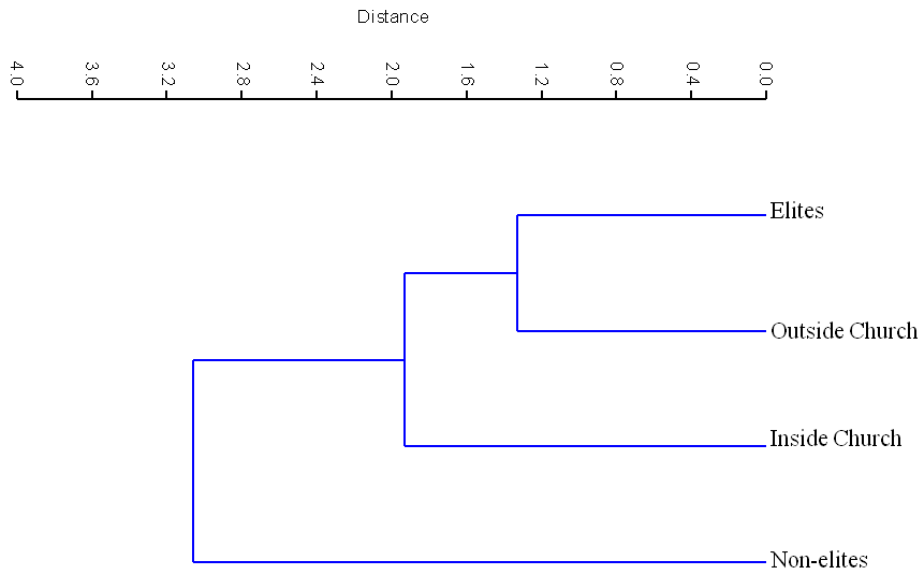
PC	Eigenvalue	% variance
1	1.88209	60.125
2	1.10822	35.403
3	0.139977	4.4717



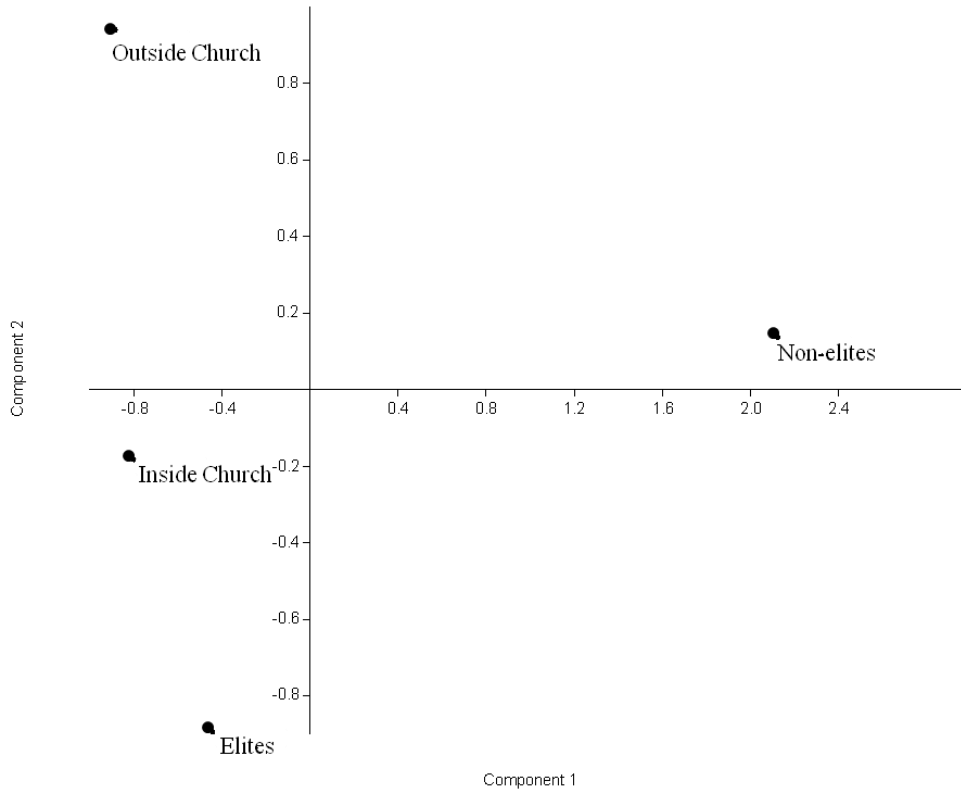
PCA and Cluster - Biceps brachii Surface Areas: Females



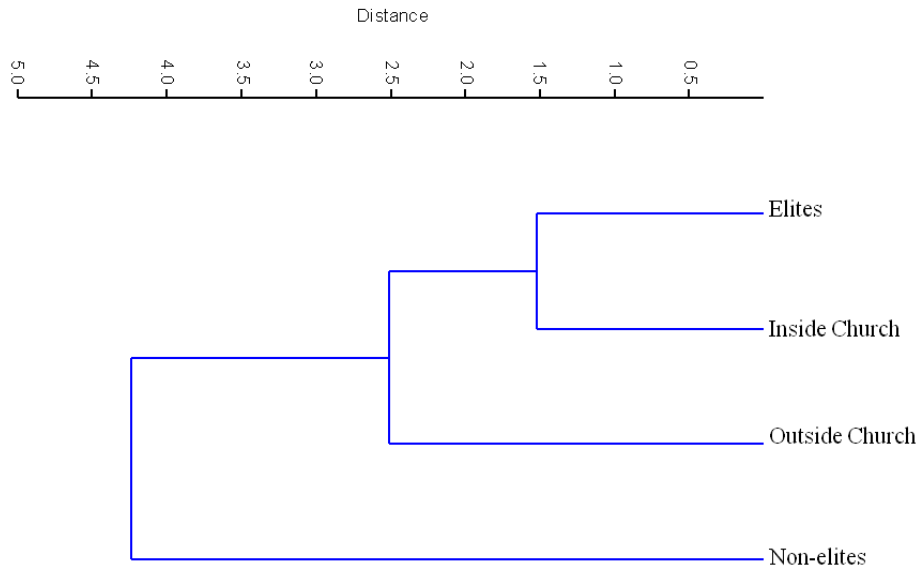
PC	Eigenvalue	% variance
1	1.9284	85.547
2	0.307985	13.663
3	0.0178233	0.79067



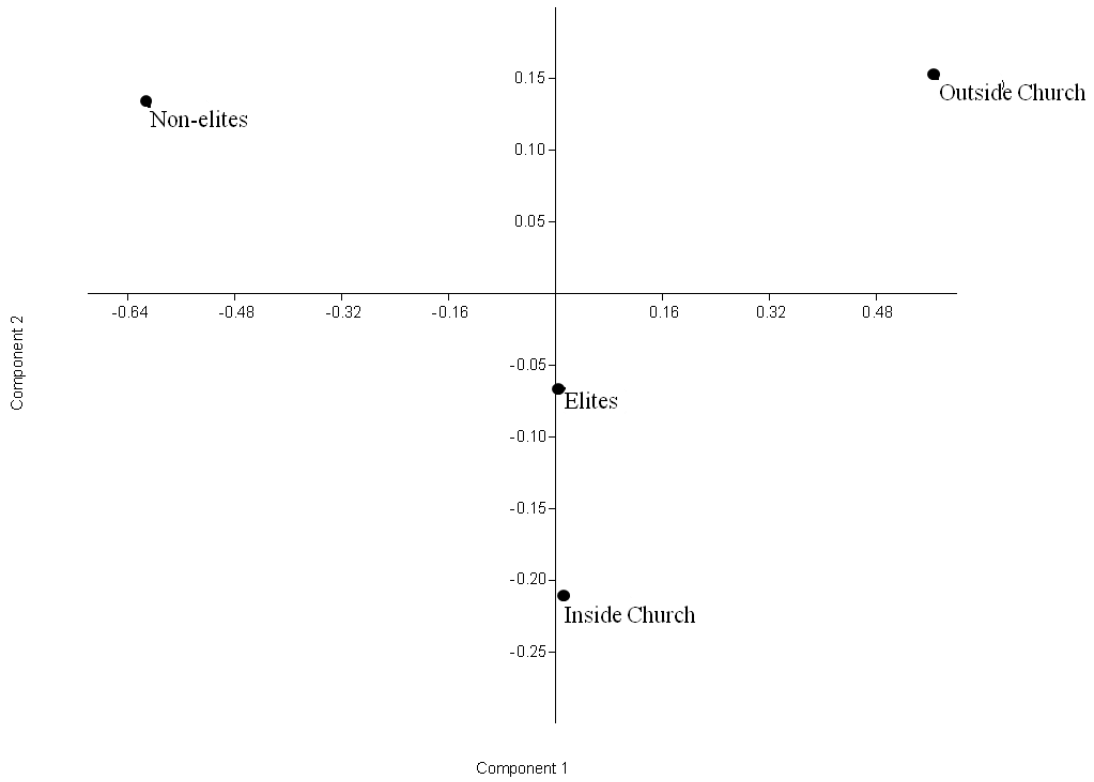
PCA and Cluster - Biceps brachii Surface Areas: Males



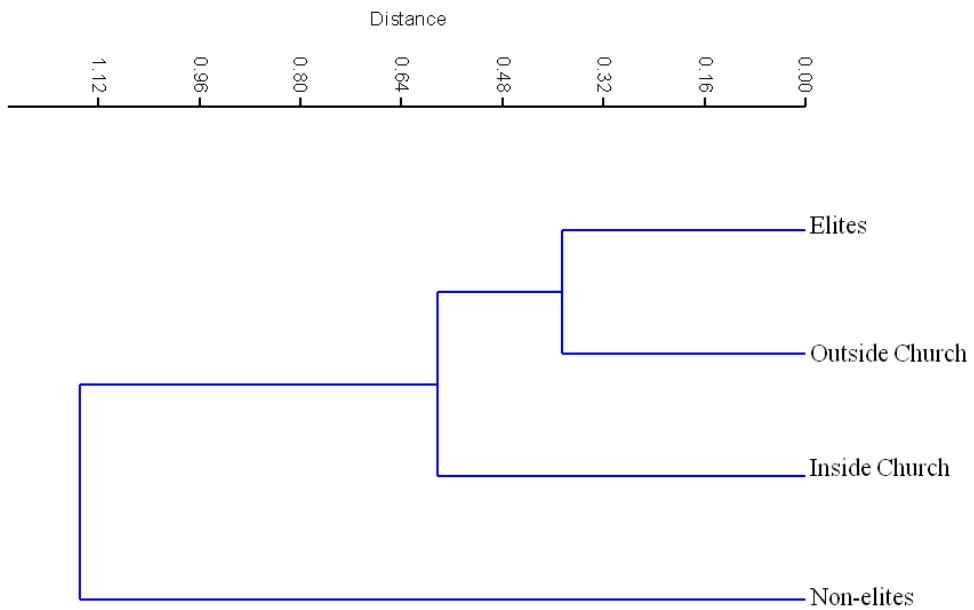
PC	Eigenvalue	% variance
1	2.03911	73.137
2	0.577516	20.714
3	0.171446	6.1492



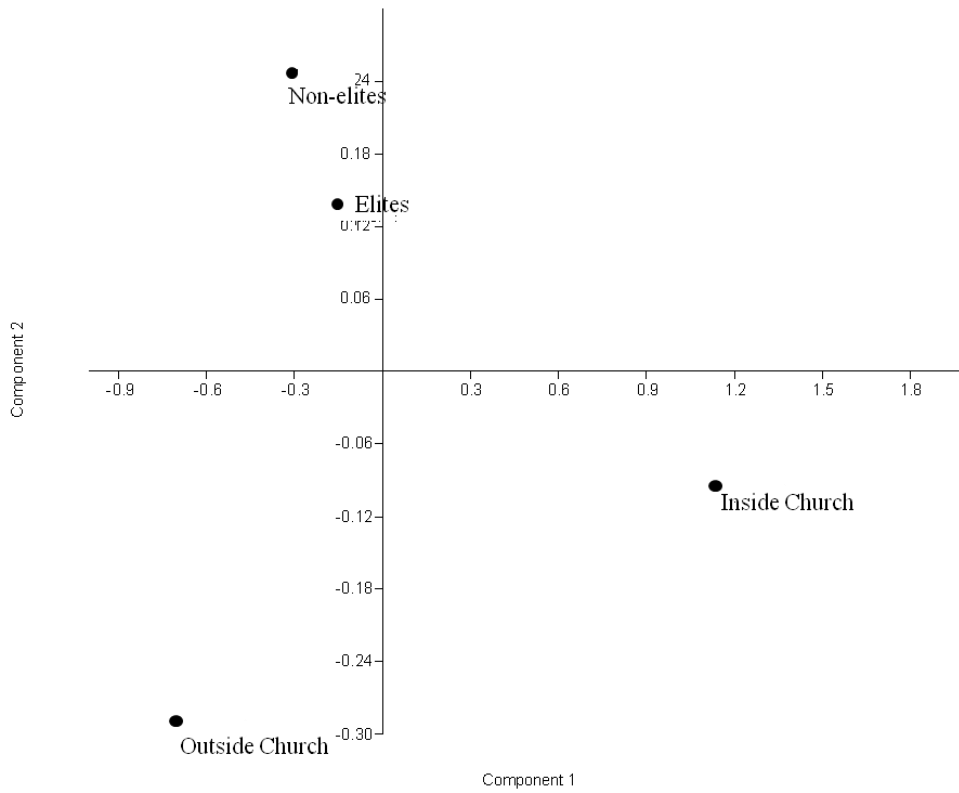
PCA and Cluster - Pronator teres Surface Areas: Females



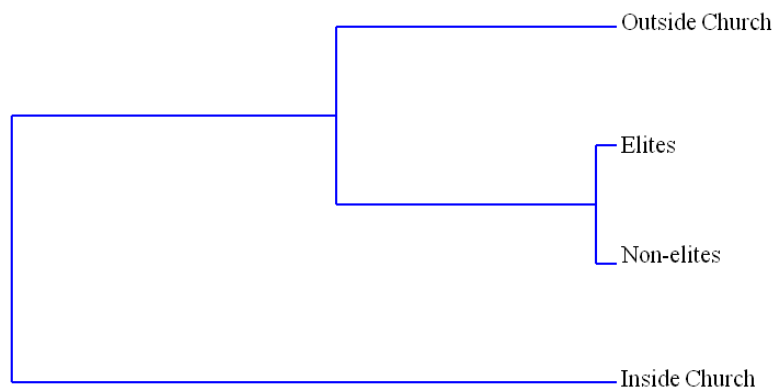
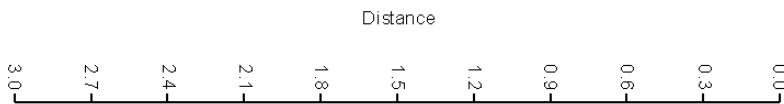
PC	Eigenvalue	% variance
1	0.232834	87.454
2	0.0303598	11.403
3	0.00304286	1.1429



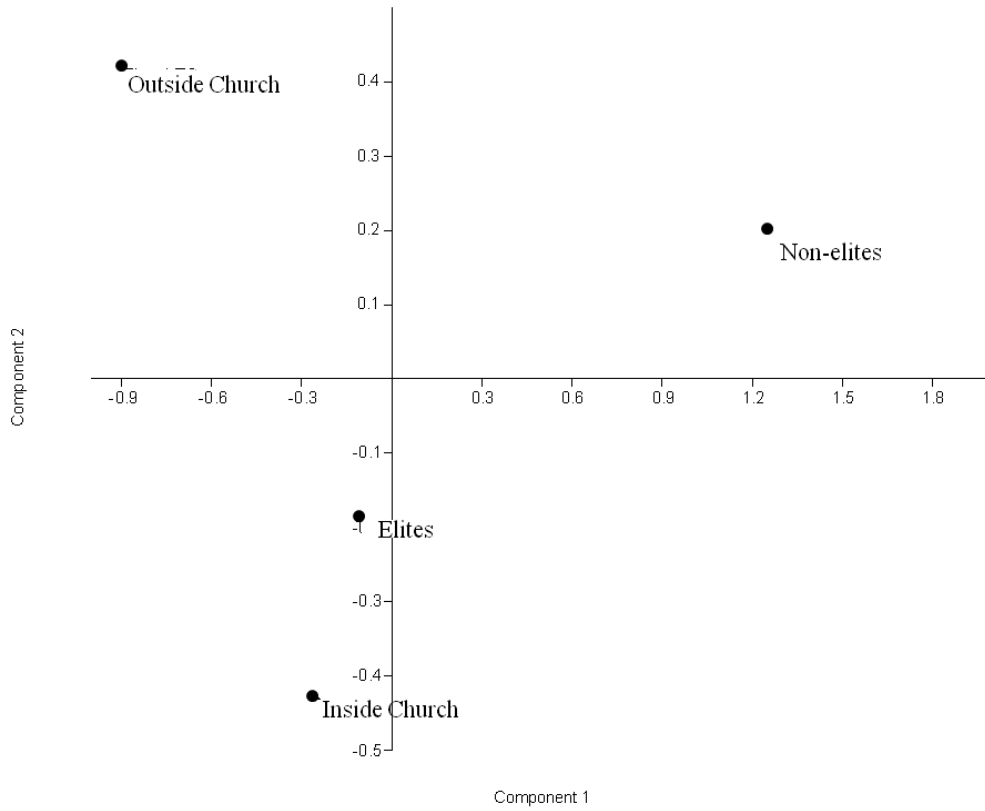
PCA and Cluster - Pronator teres Surface Areas: Males



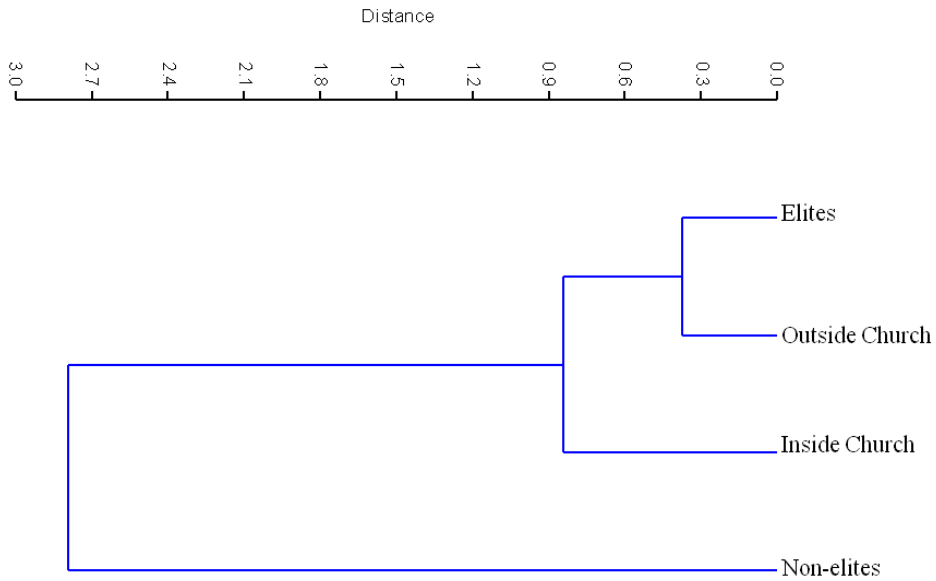
PC	Eigenvalue	% variance
1	0.636555	89.986
2	0.0573223	8.1033
3	0.0135184	1.911



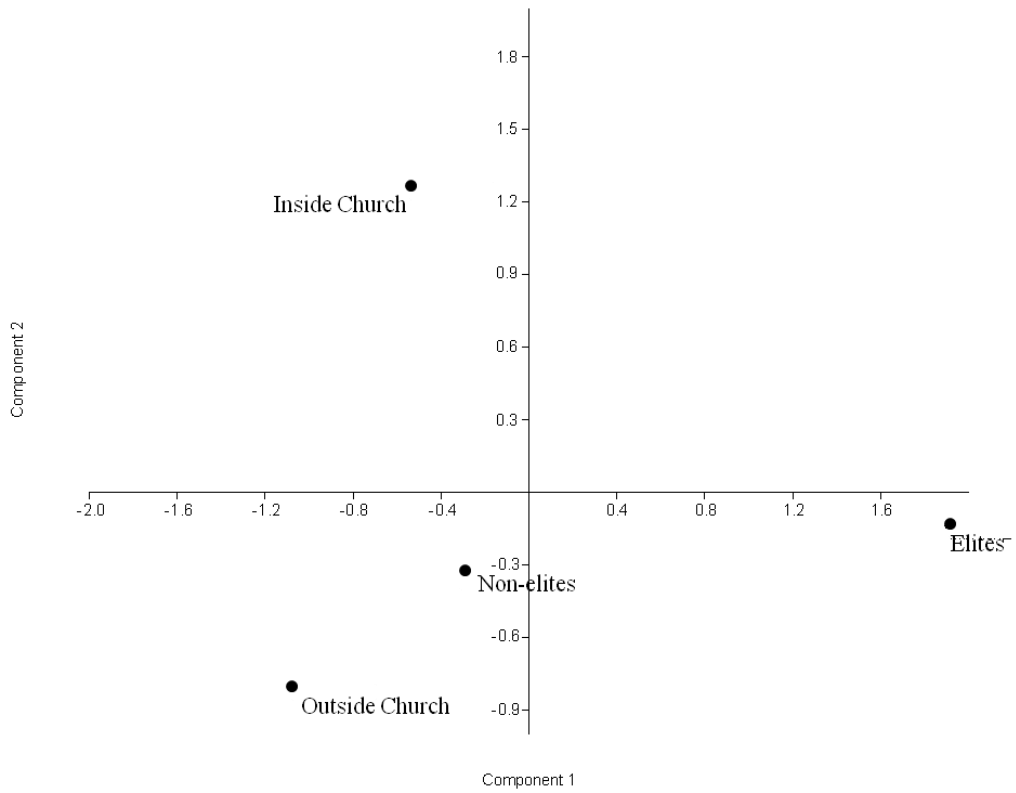
PCA and Cluster - Brachialis Surface Areas: Females



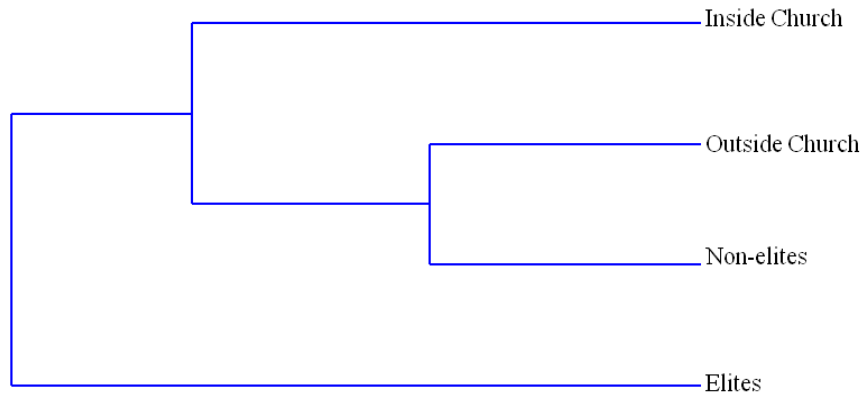
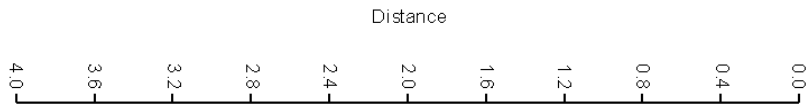
PC	Eigenvalue	% variance
1	0.816378	84.72
2	0.146867	15.241
3	0.000372739	0.038681



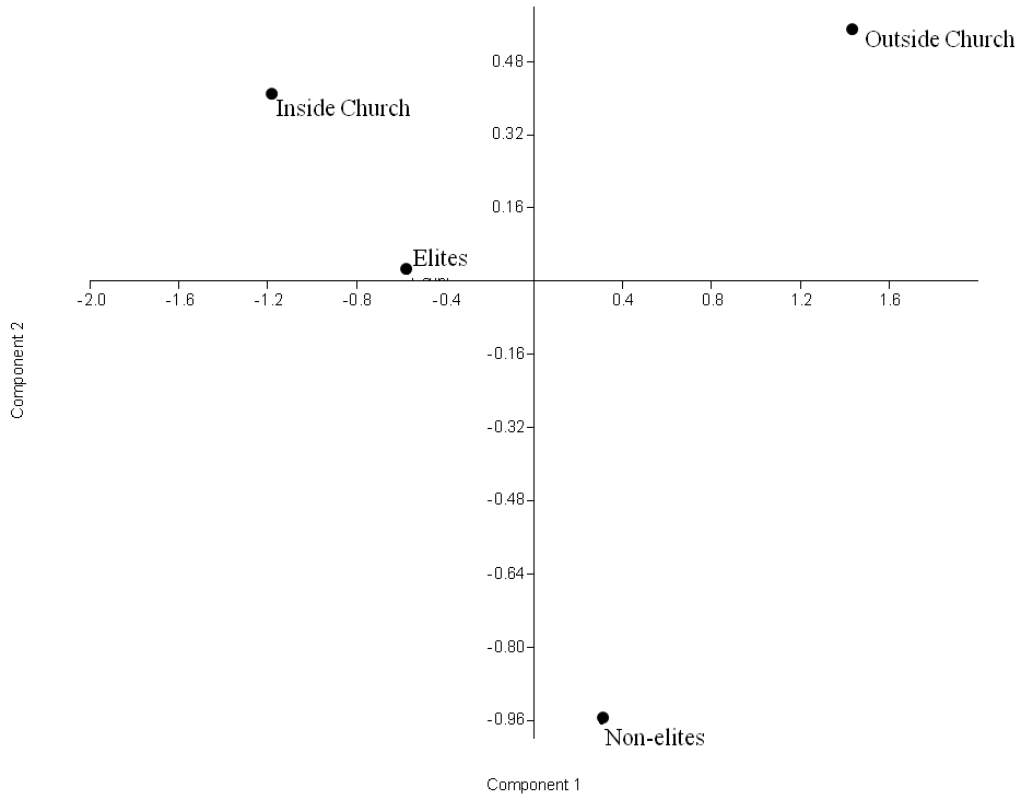
PCA and Cluster - Brachialis Surface Areas: Males



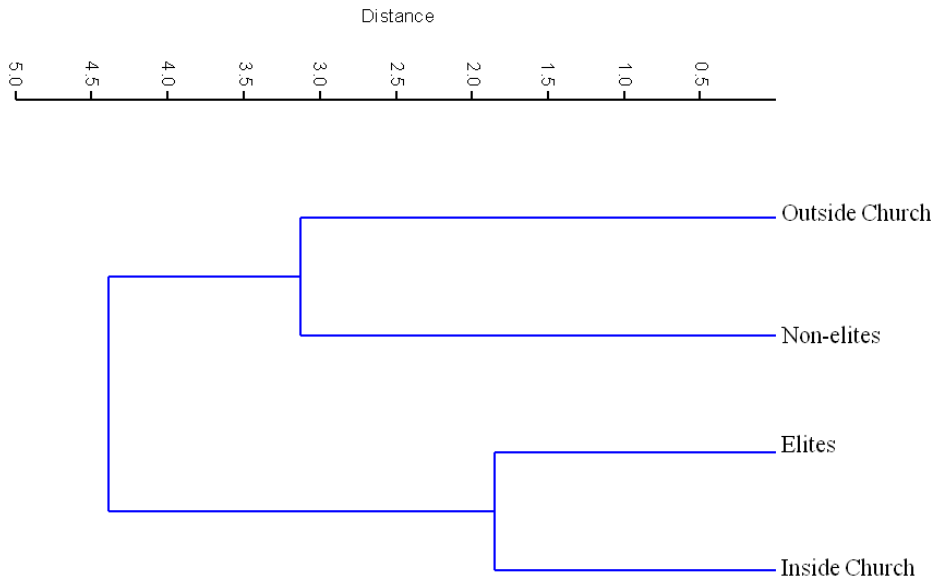
PC	Eigenvalue	% variance
1	1.71556	63.287
2	0.791607	29.202
3	0.203594	7.5106



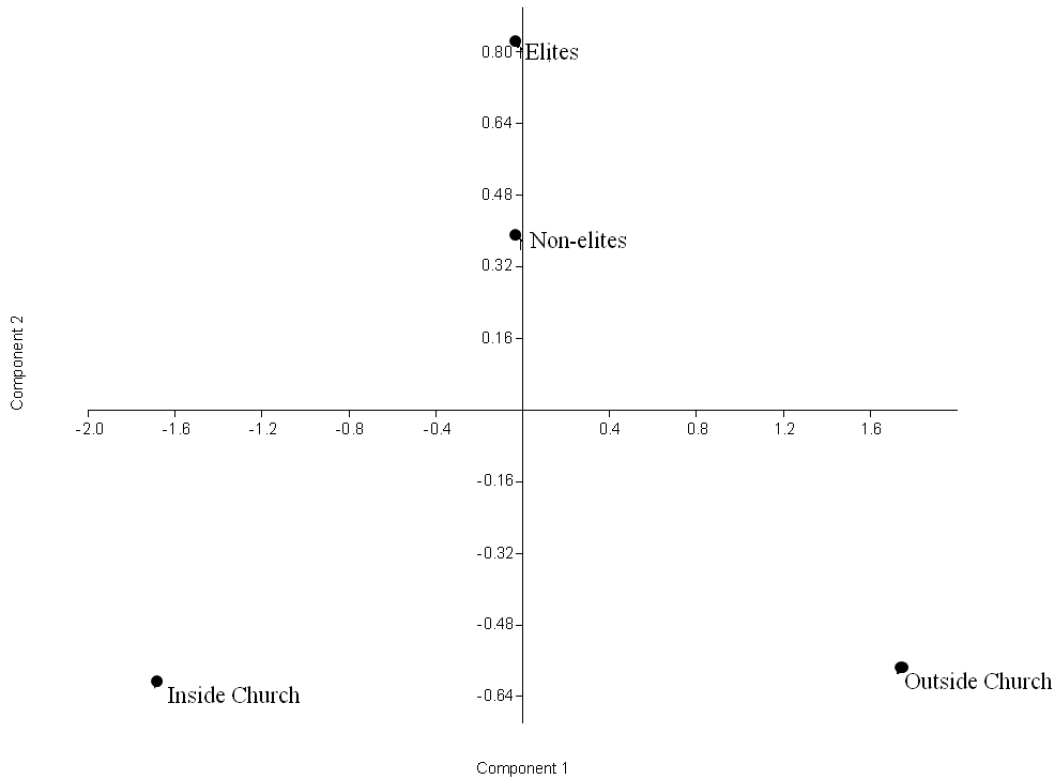
PCA and Cluster - Supinator Surface Areas: Females



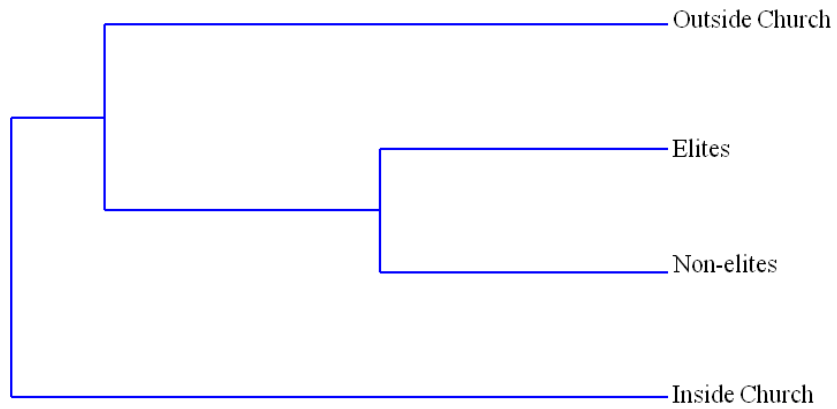
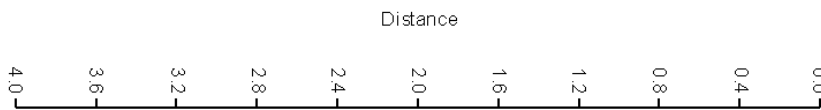
PC	Eigenvalue	% variance
1	1.30074	73.152
2	0.459976	25.868
3	0.0174216	0.97977



PCA and Cluster - Supinator Surface Areas: Males

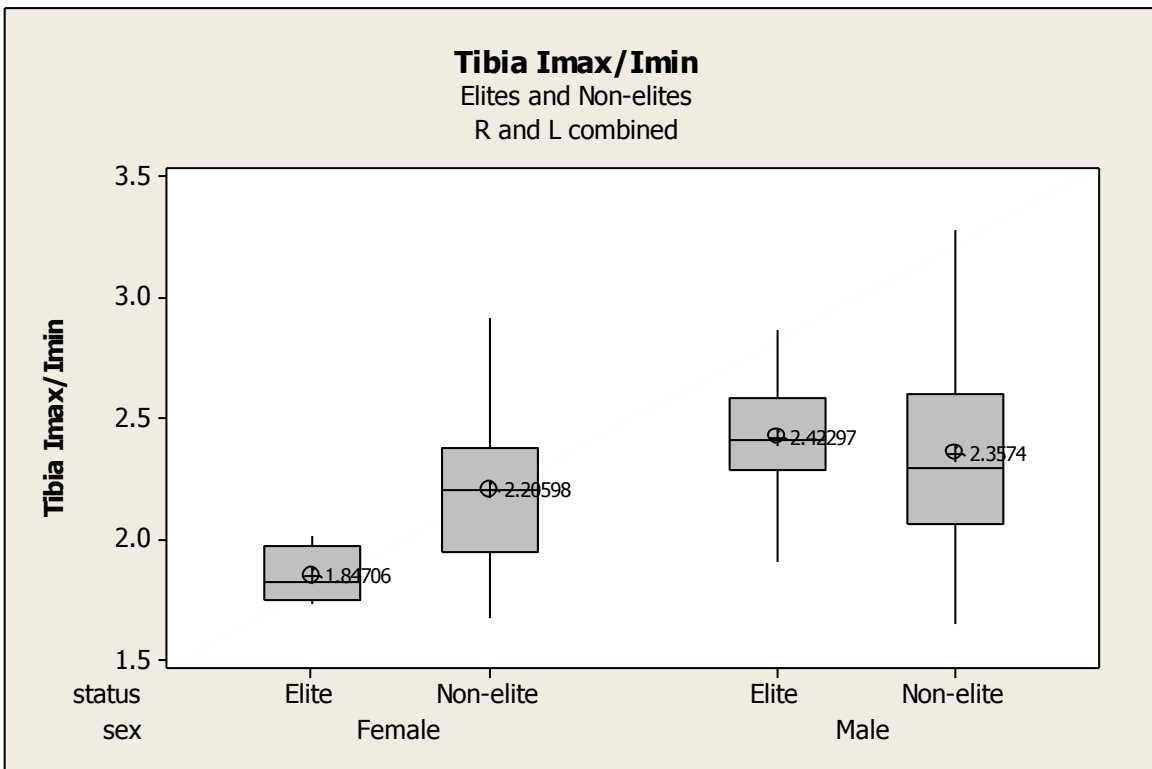
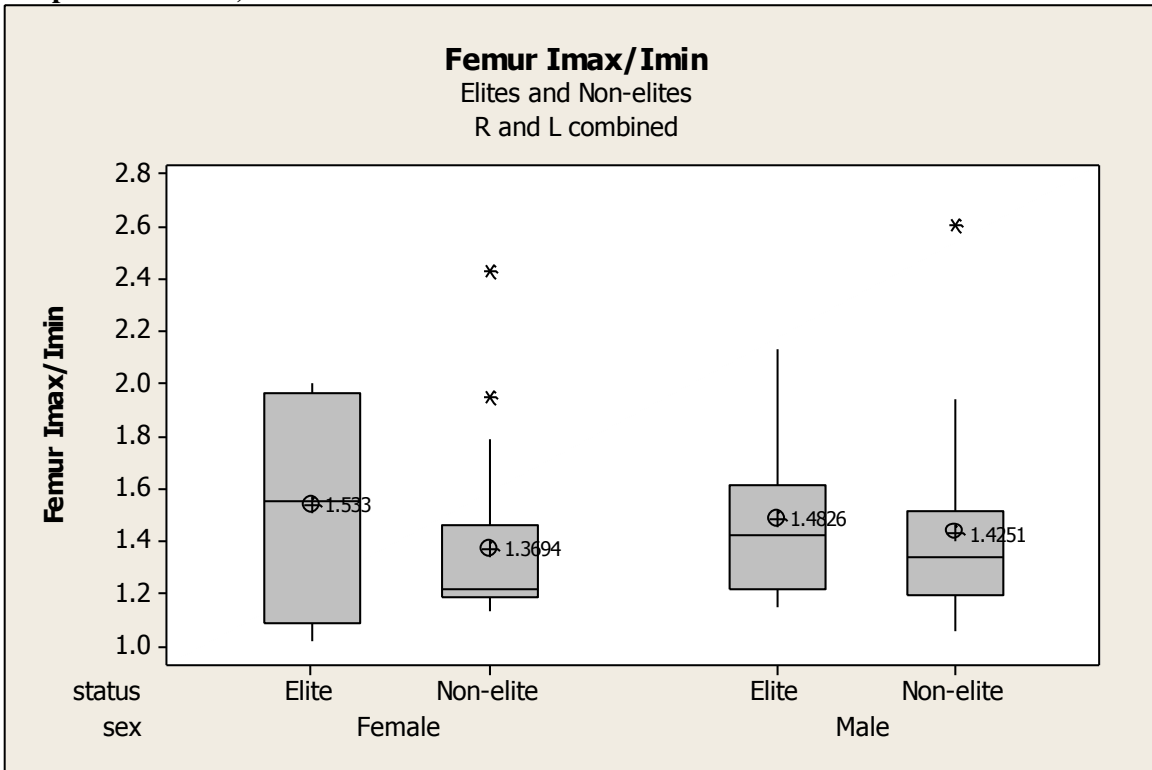


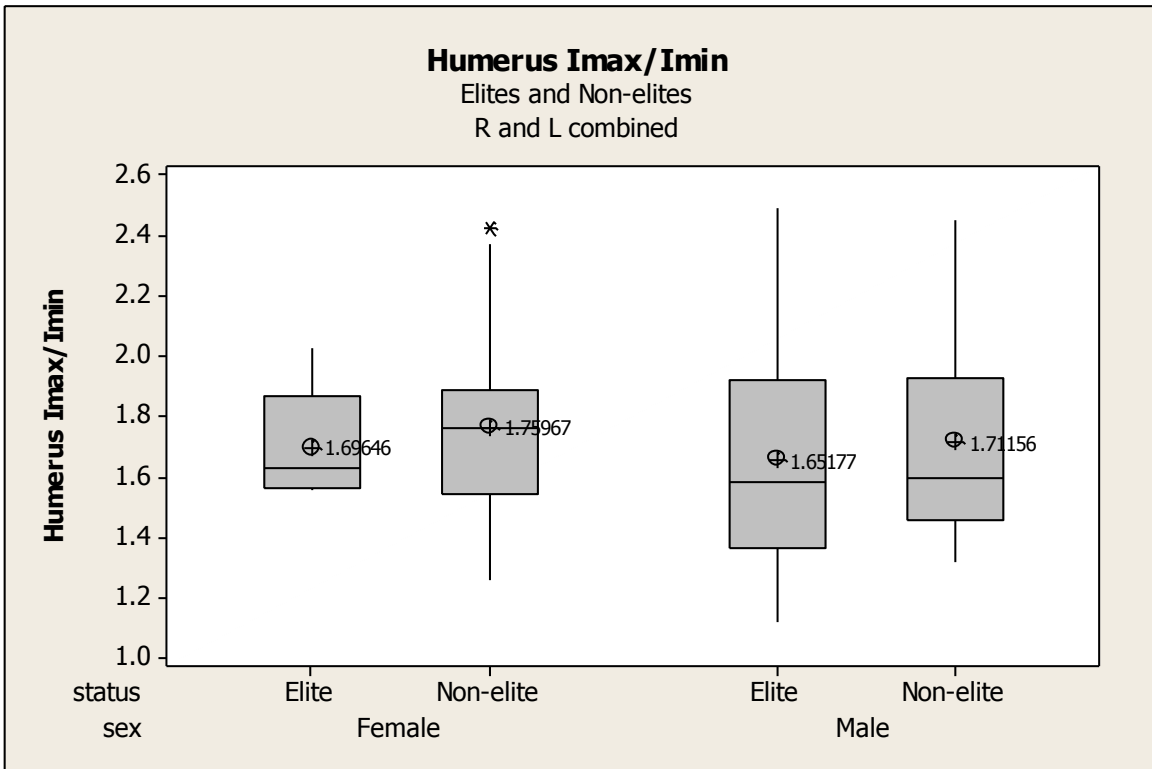
PC	Eigenvalue	% variance
1	1.94629	77.012
2	0.512803	20.291
3	0.0681482	2.6966



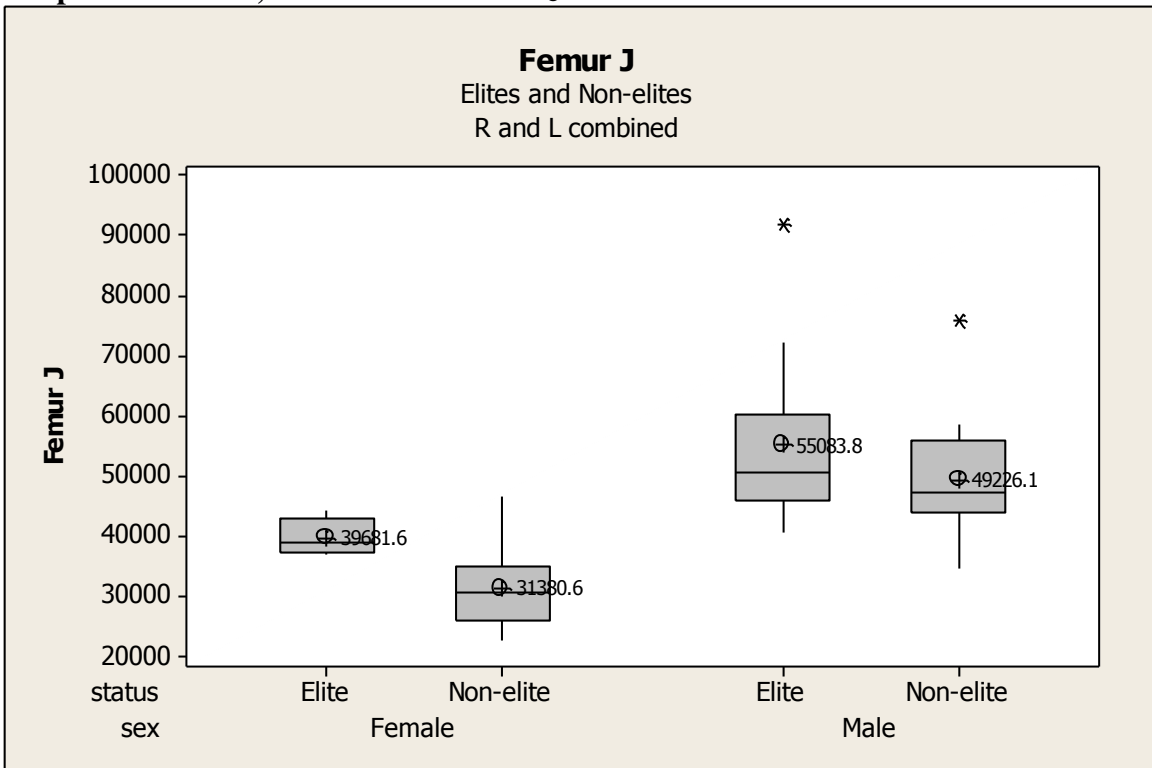
**Appendix 3A: Boxplots of Cross-sectional Properties of the Femur, Tibia and Humerus
Male and Female Elites and Non-elites with Means Labeled**

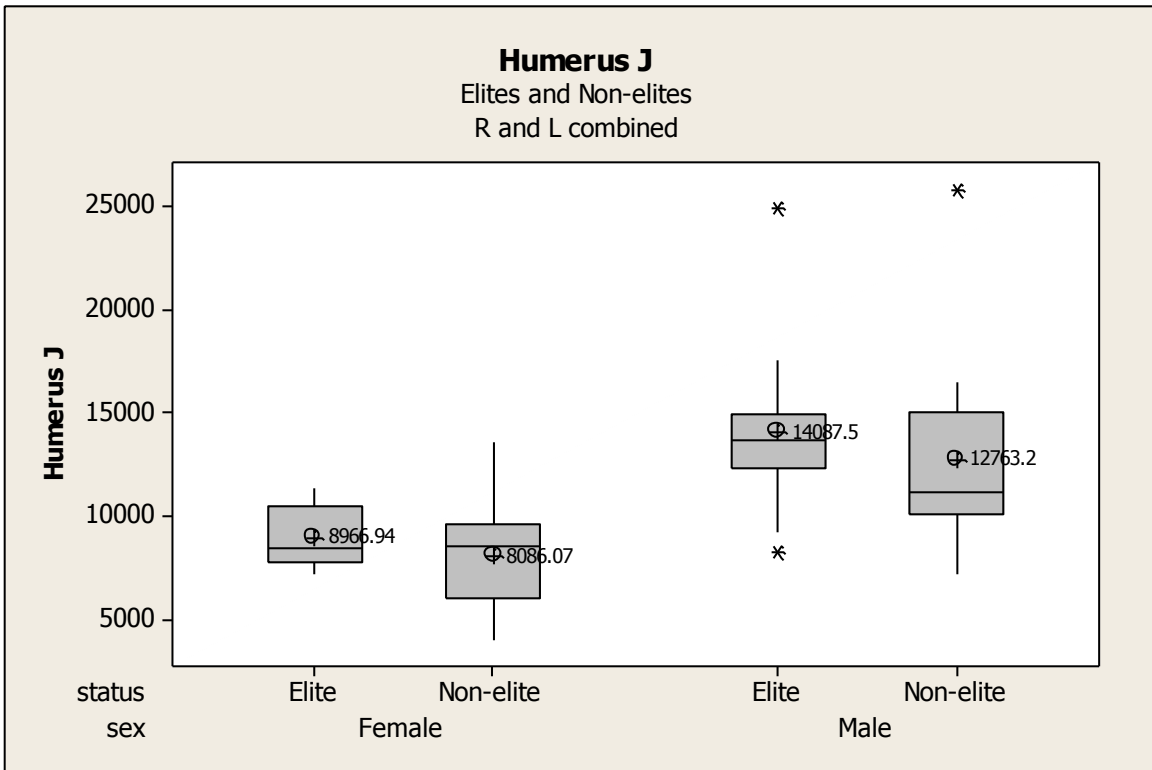
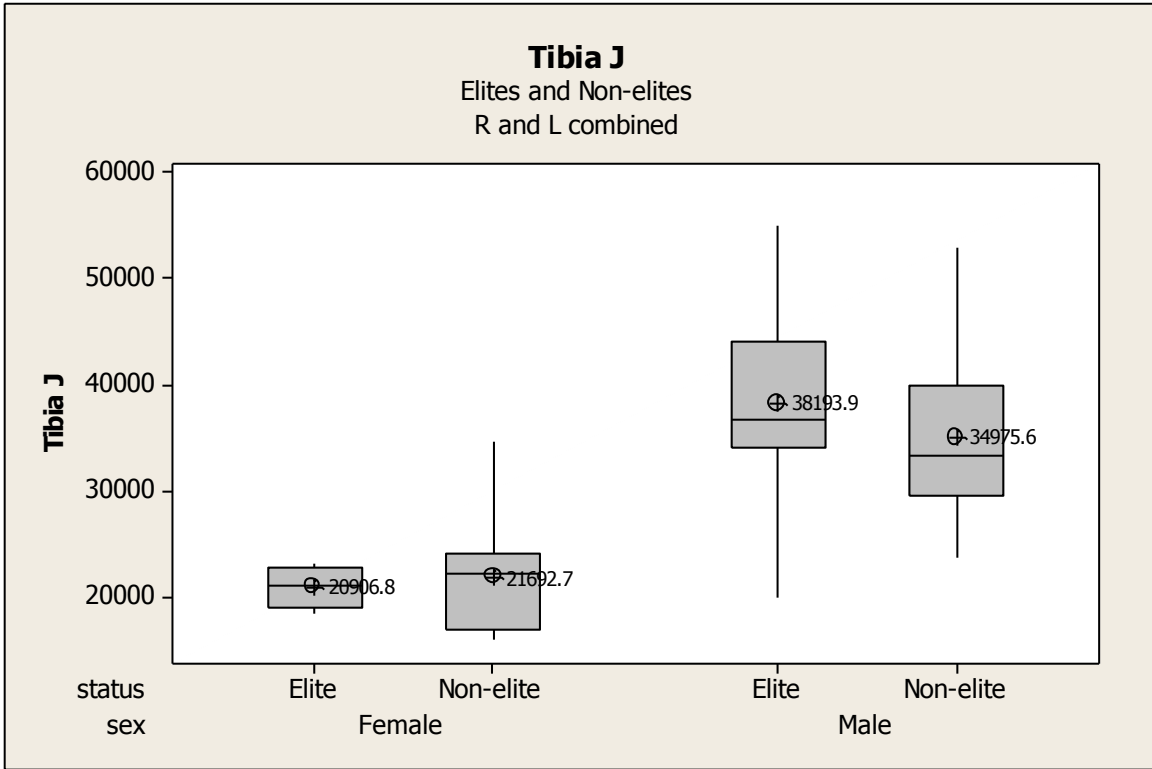
Boxplots of Femur, Tibia and Humerus *I*_{max}/*I*_{min}



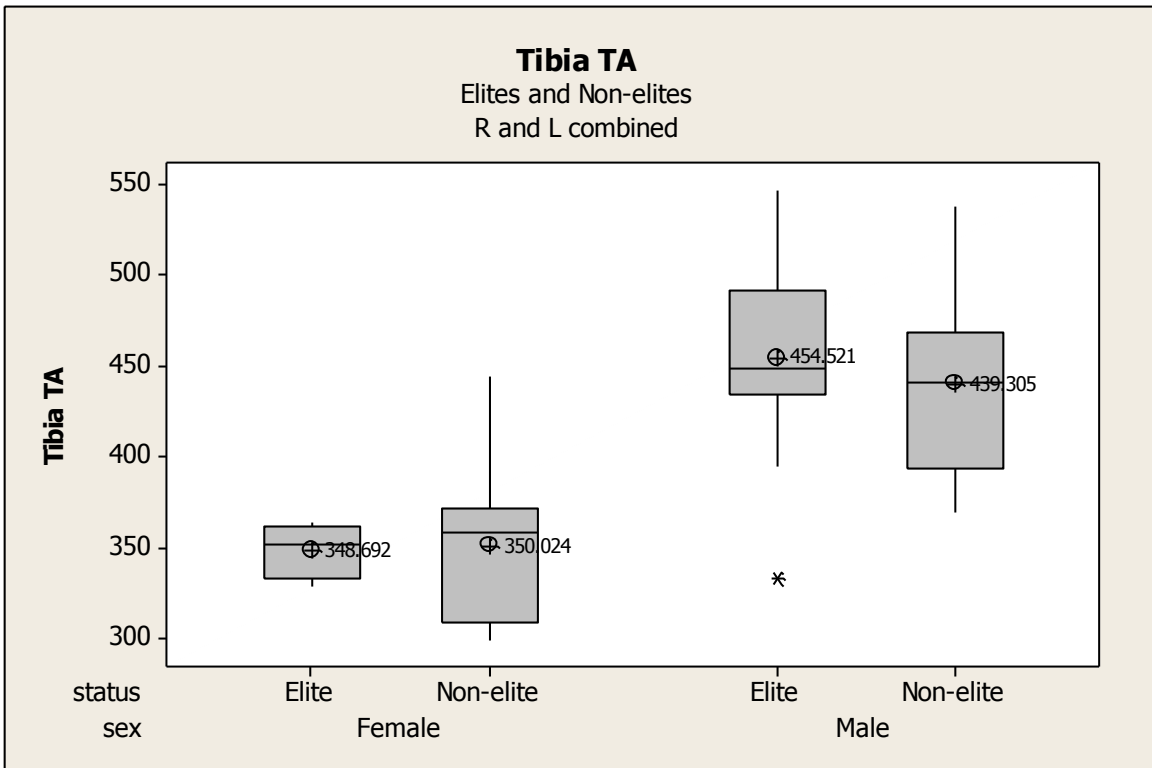
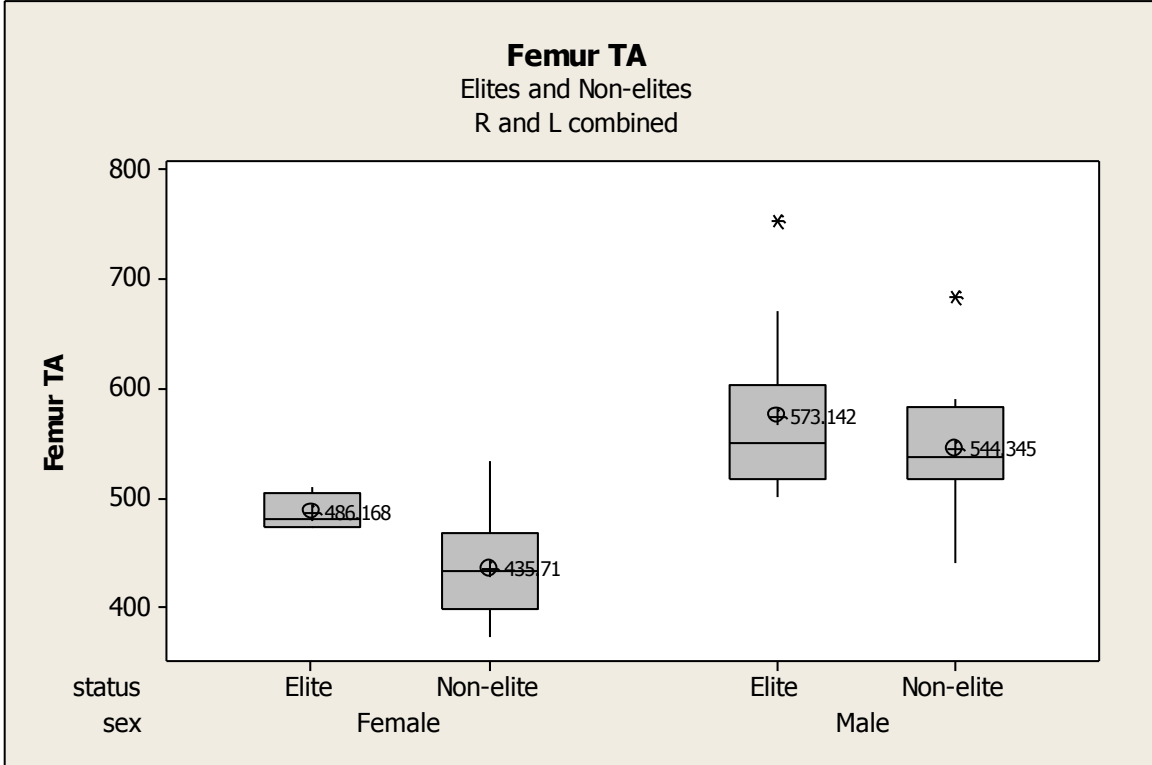


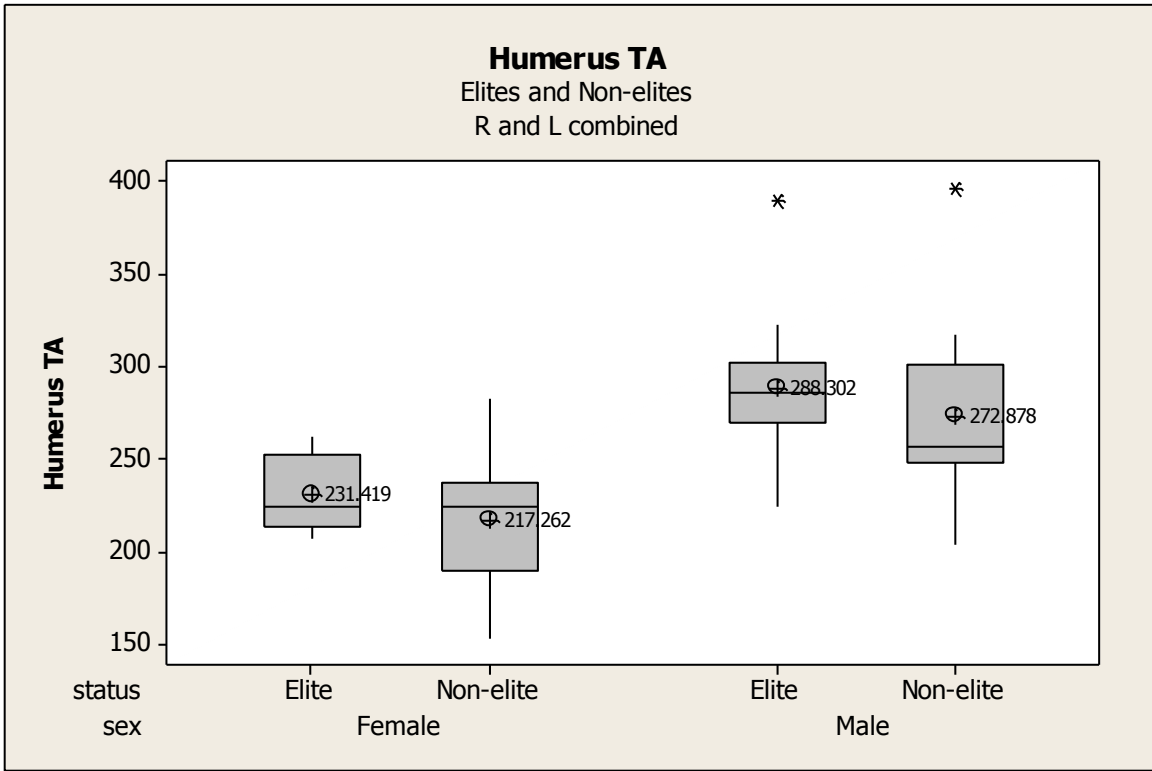
Boxplots of Femur, Tibia and Humerus *J*





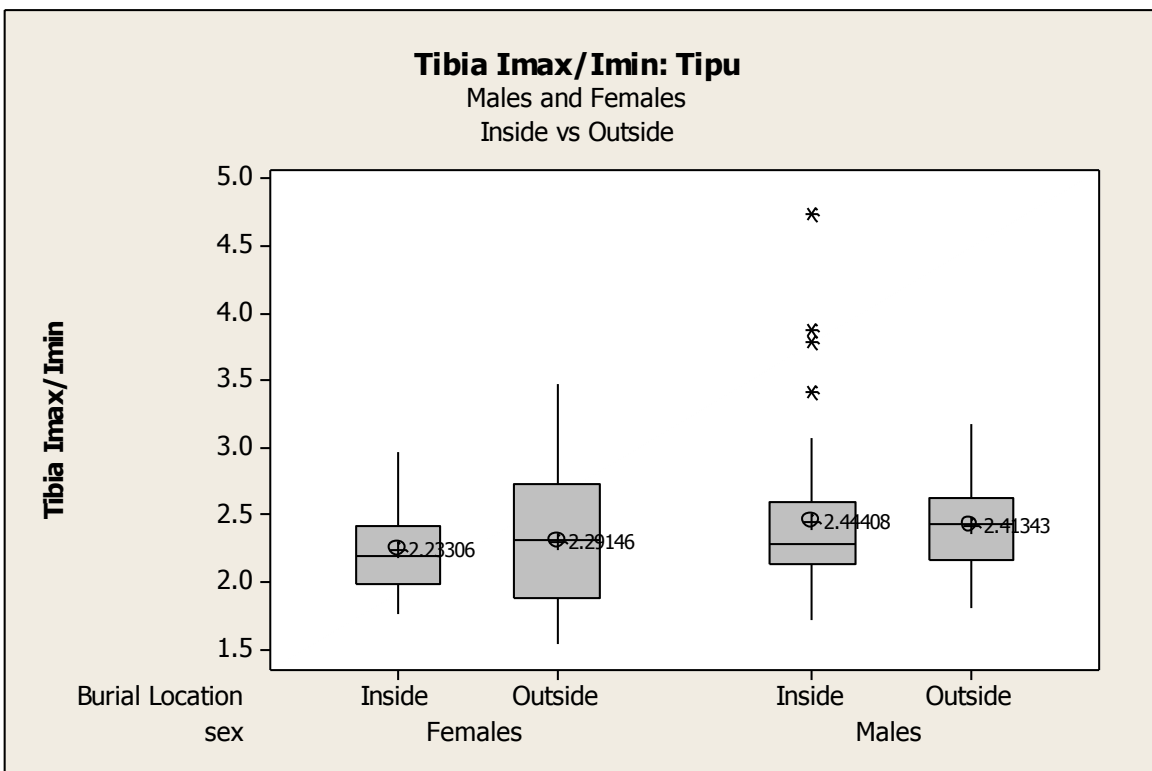
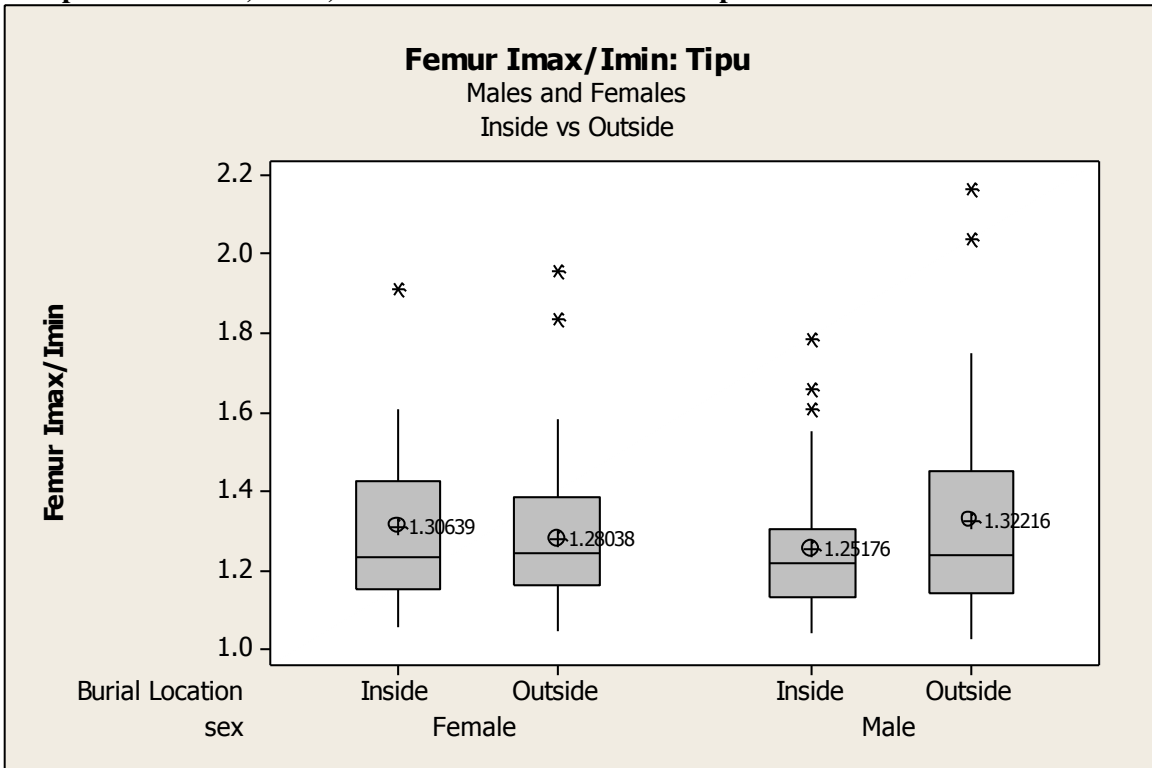
Boxplots of Femur, Tibia and Humerus TA

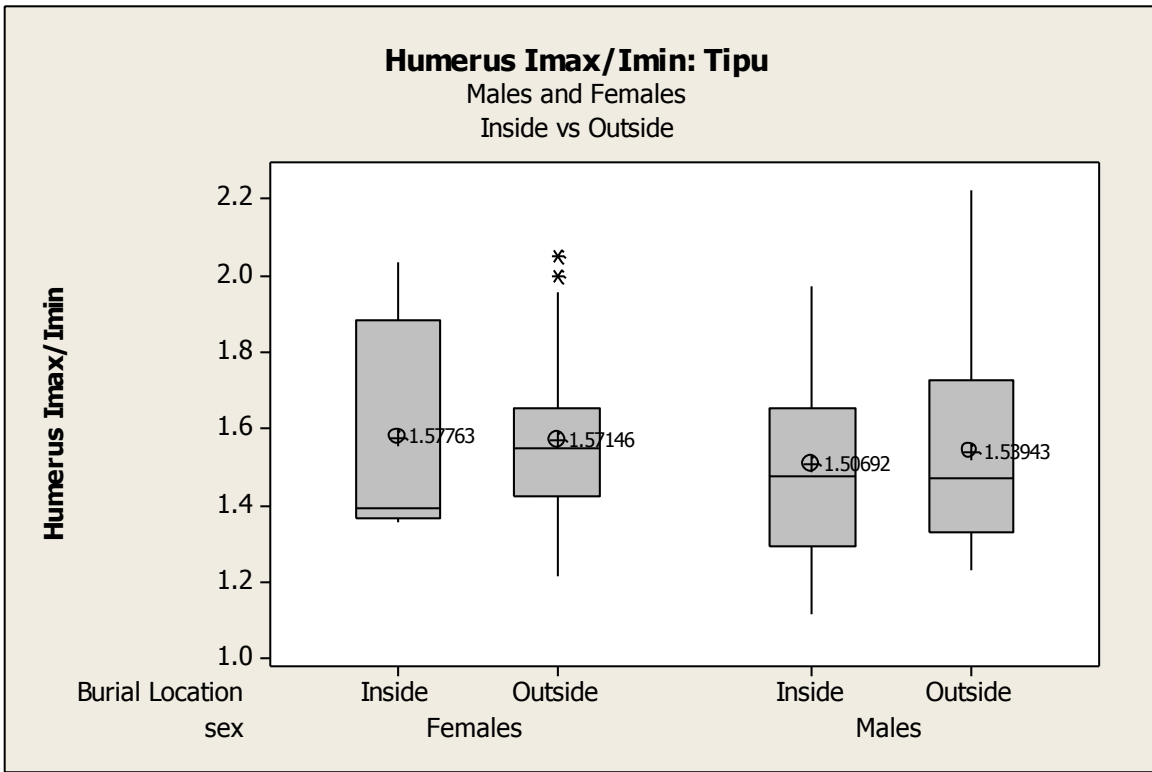




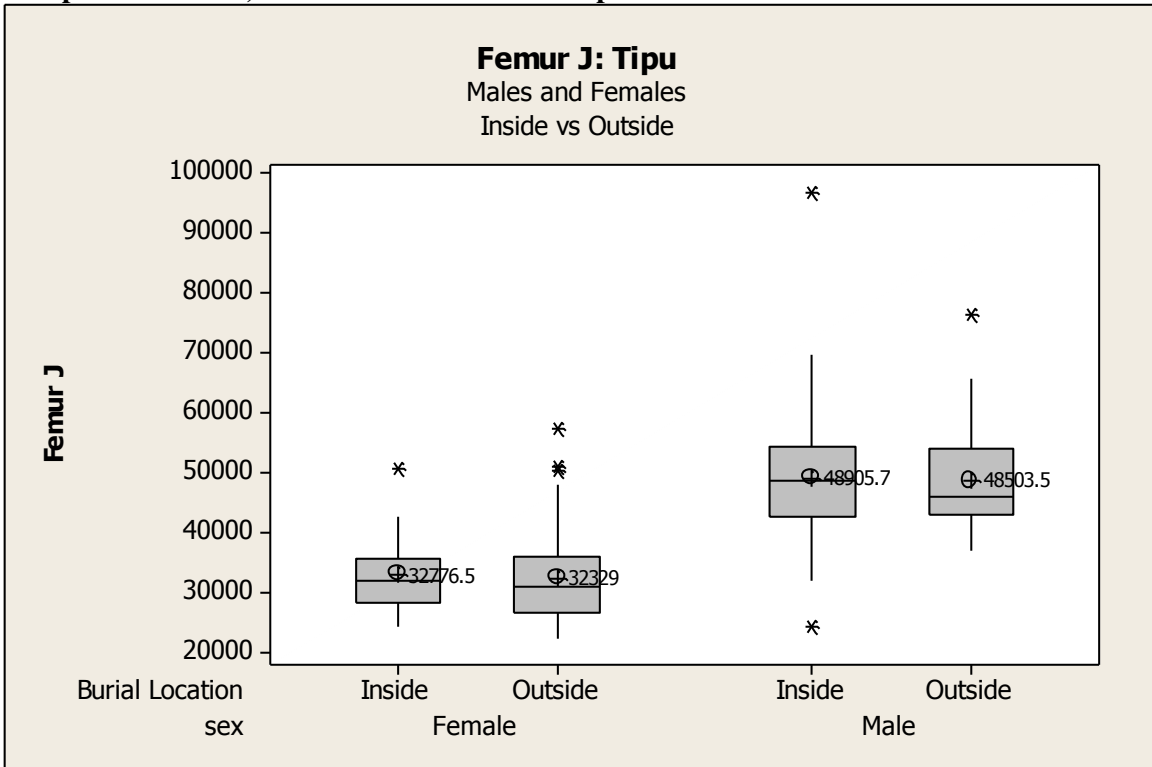
Appendix 3B: Box-plots of Cross-sectional Properties of the Femur, Tibia and Humerus for Tipu Males and Females of General Burial Groups with Means Labeled

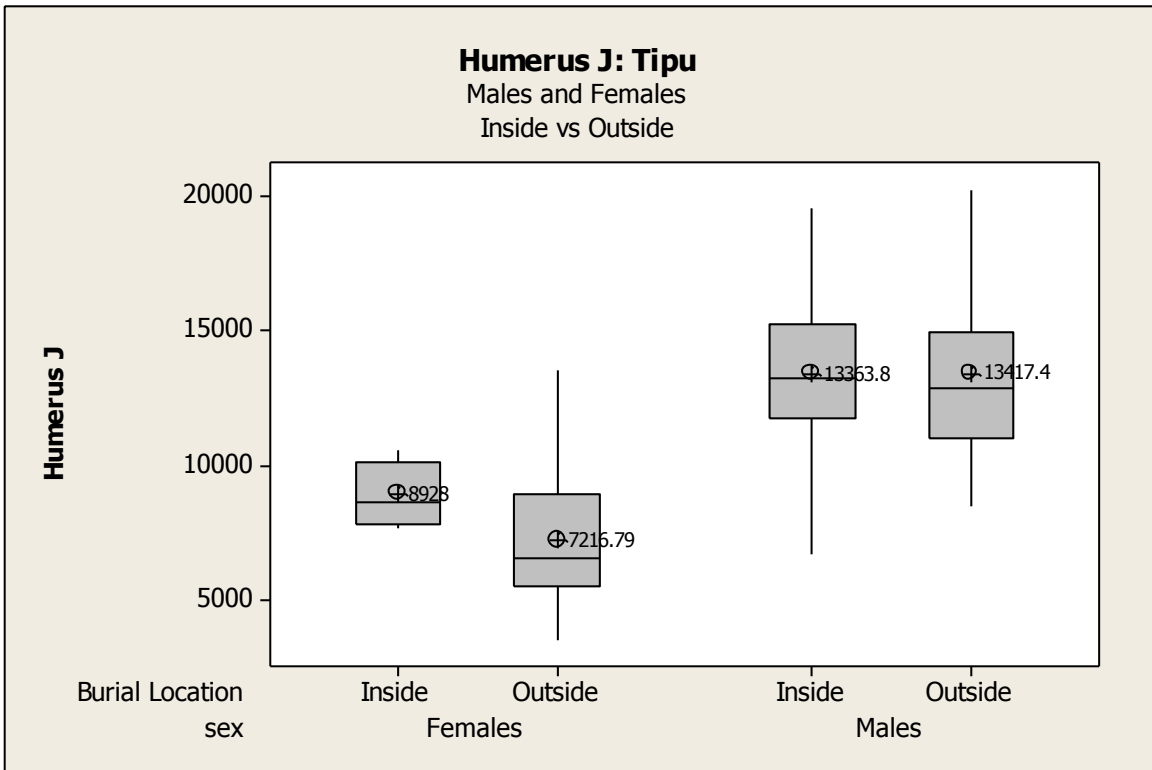
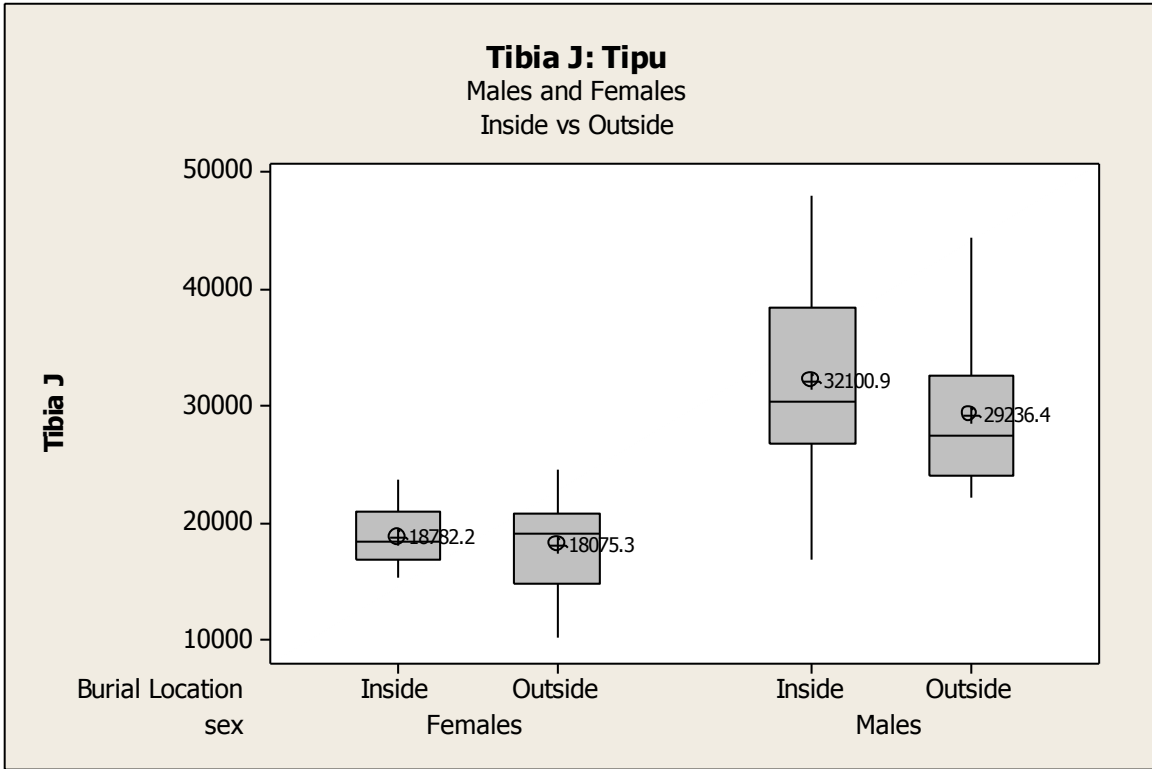
Box-plots of Femur, Tibia, and Humerus *I*_{max}/*I*_{min} at Tipu



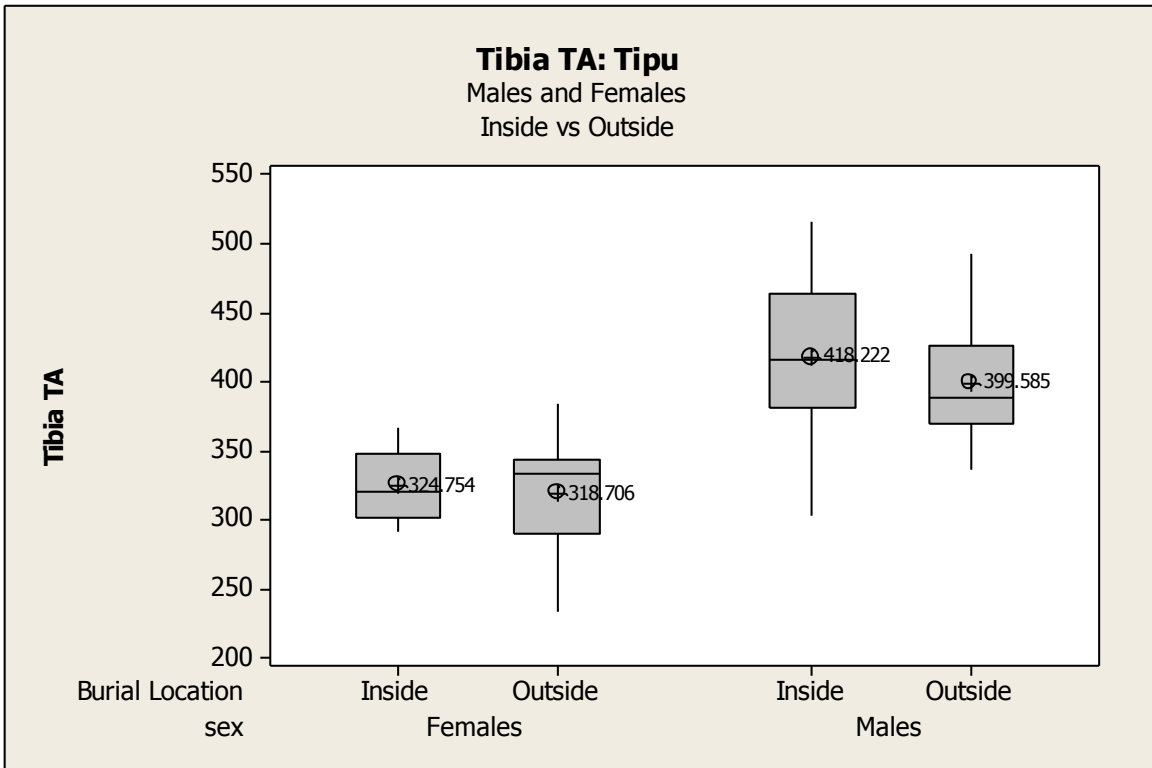
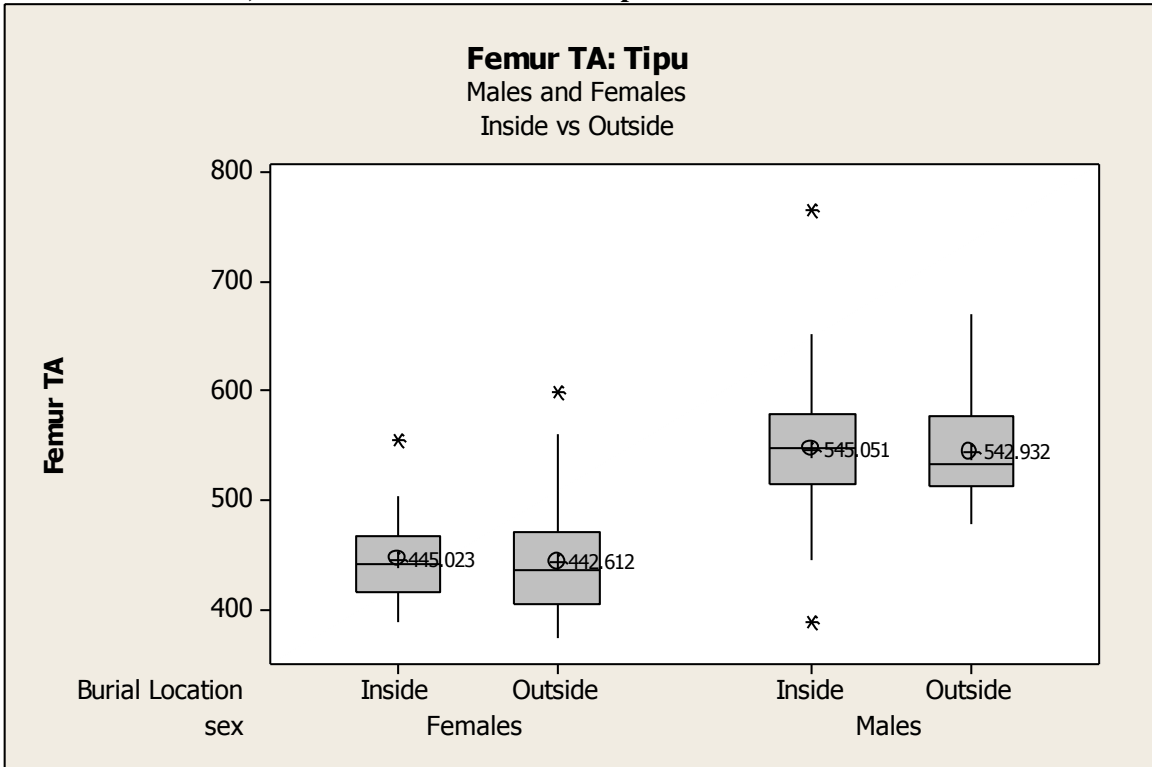


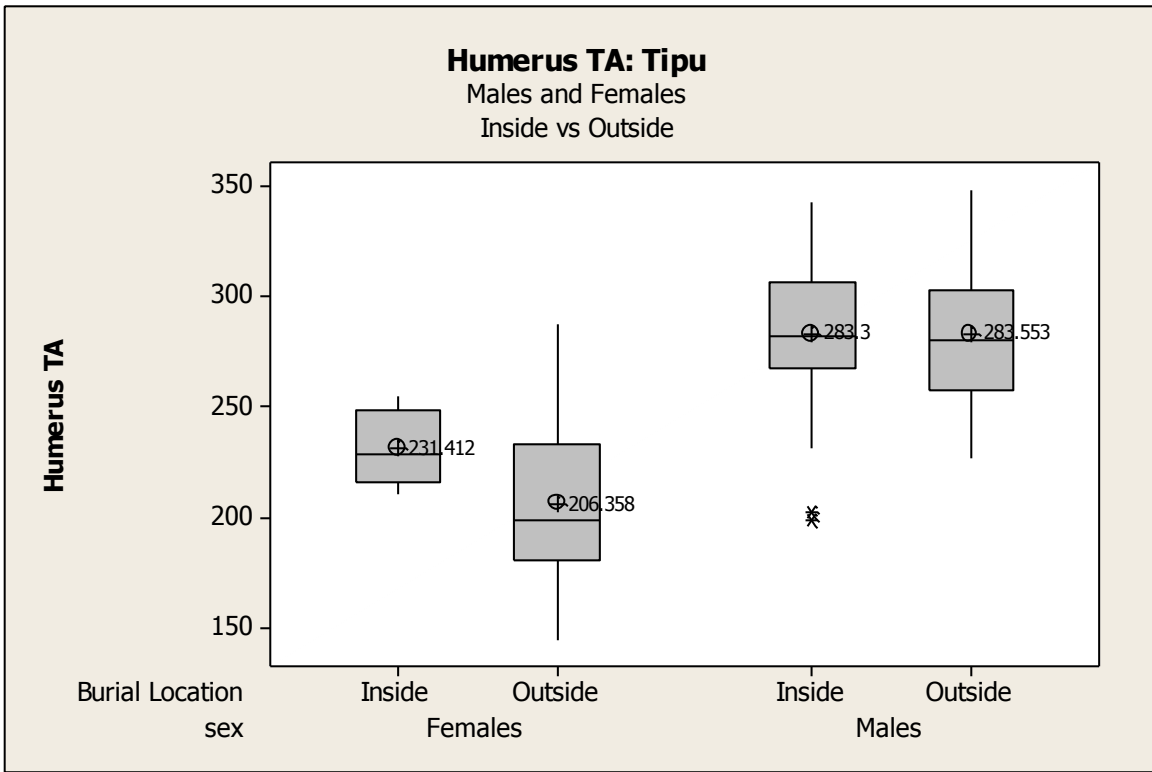
Box-plots of Femur, Tibia and Humerus J at Tipu





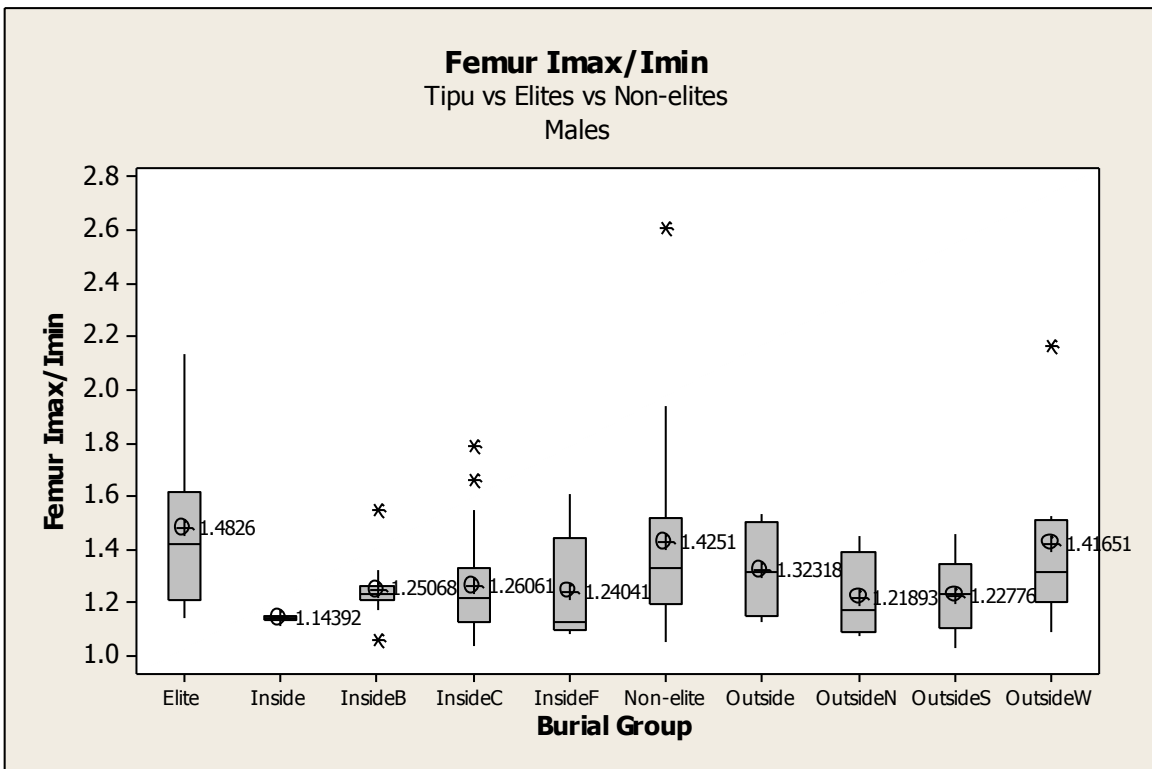
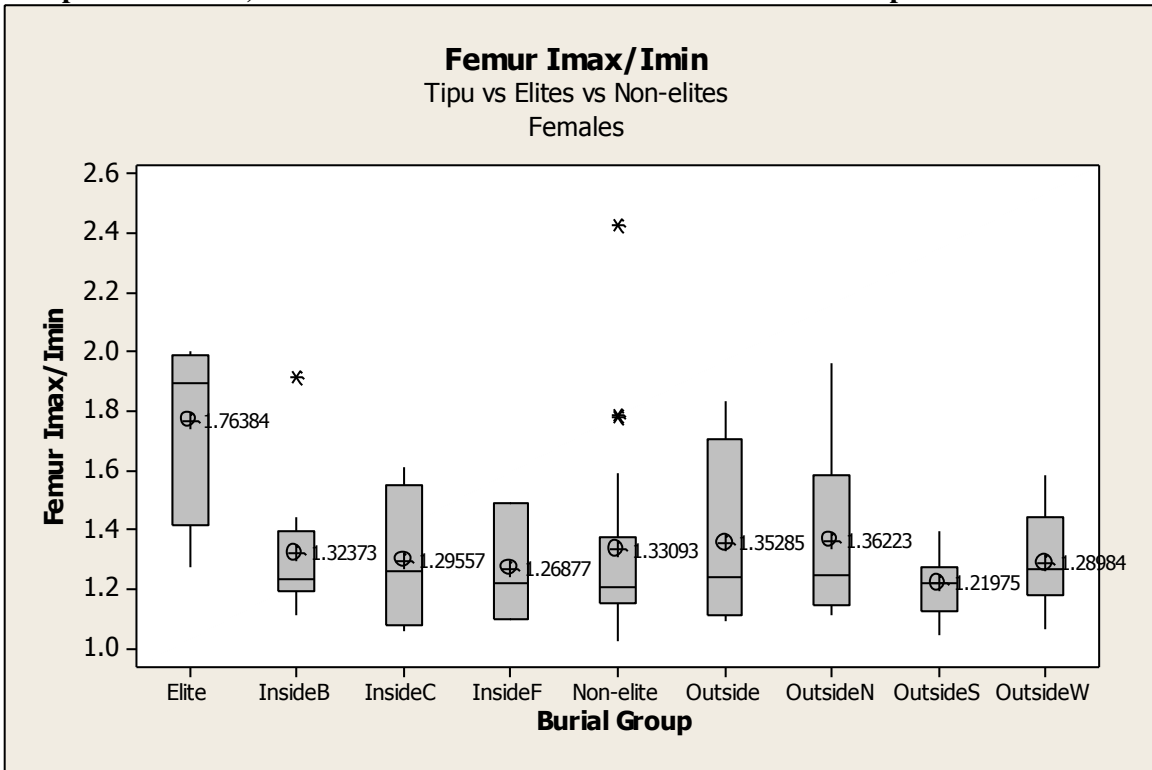
Box-Plots of Femur, Tibia and Humerus TA at Tipu

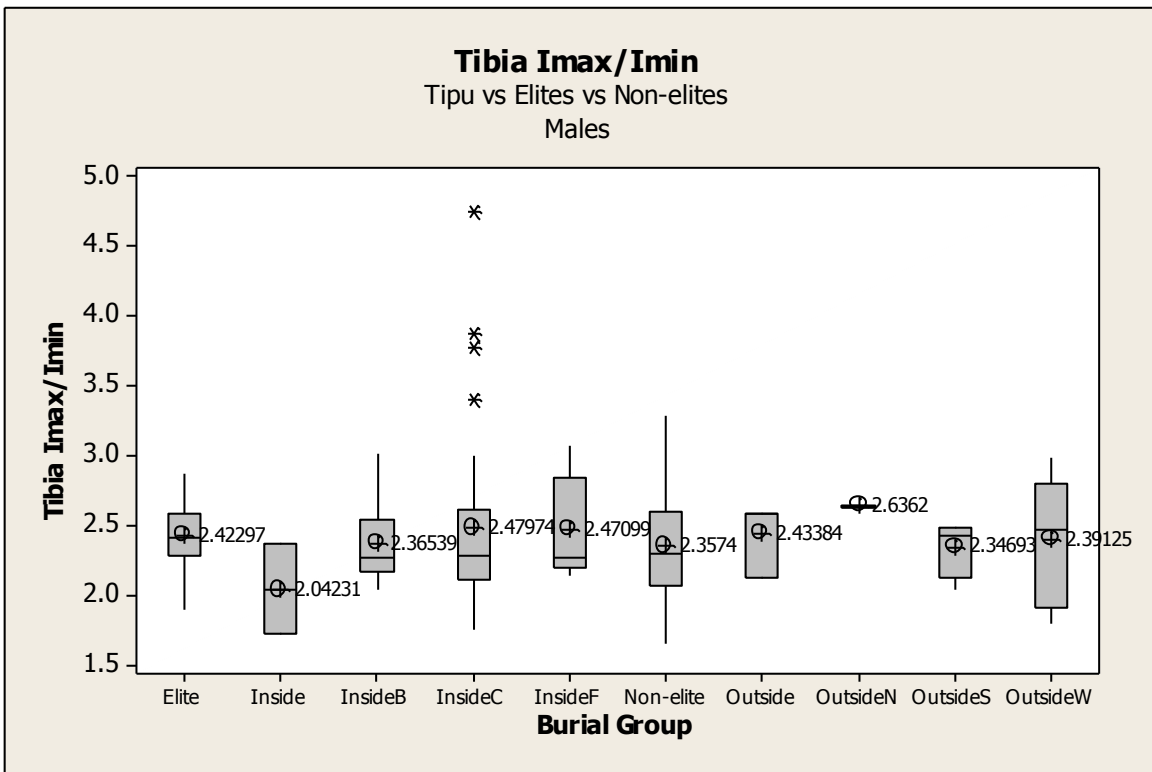
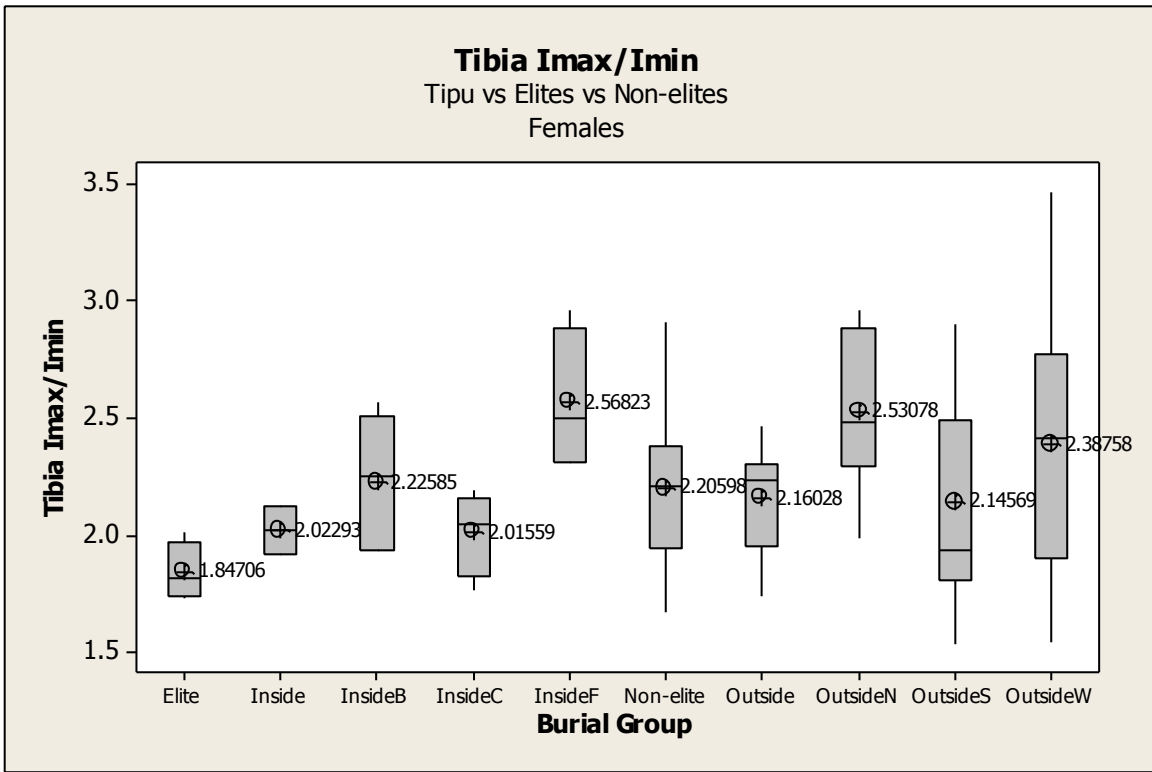


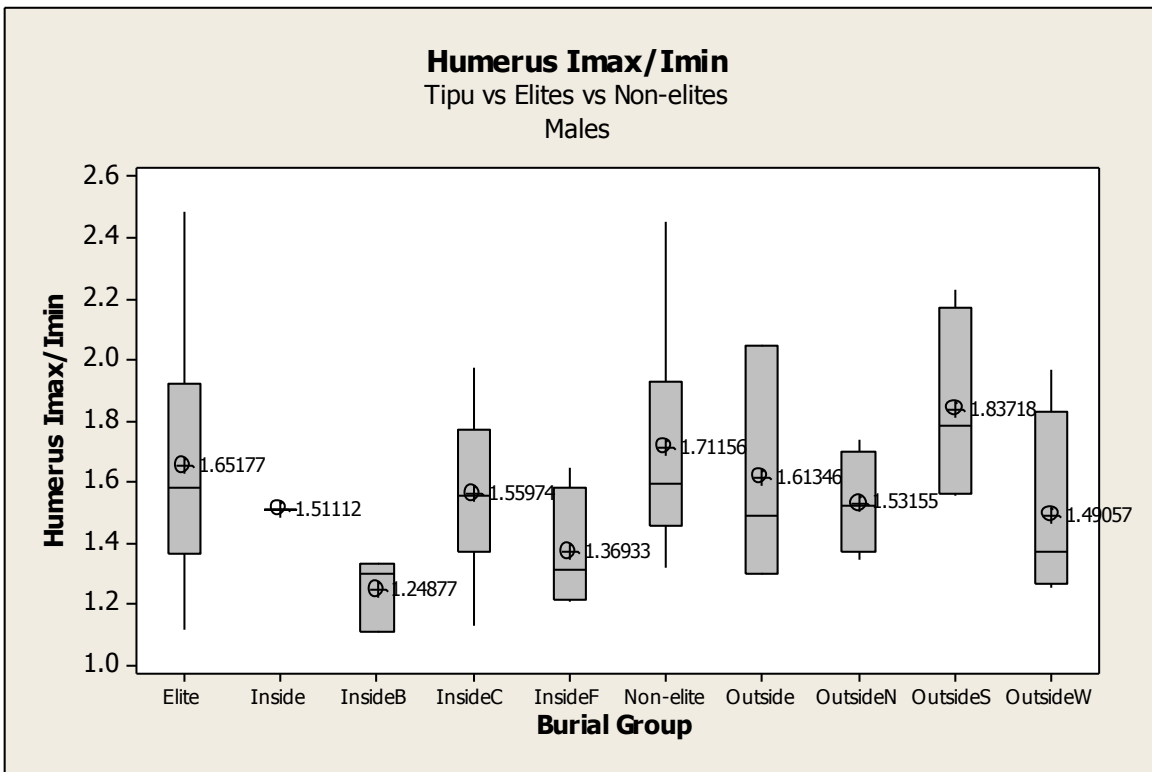
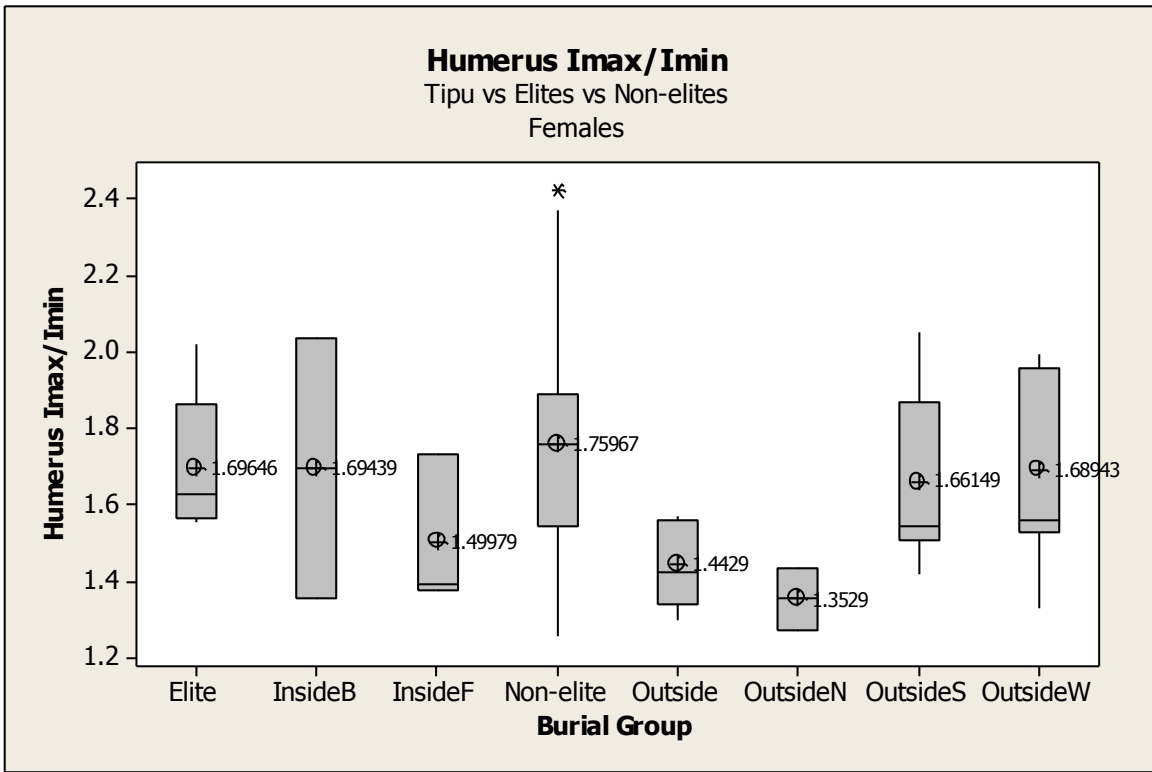


Appendix 3C: Box-plots of Cross-sectional Properties of the Femur, Tibia and Humerus for all Burial Groups with Means Labeled

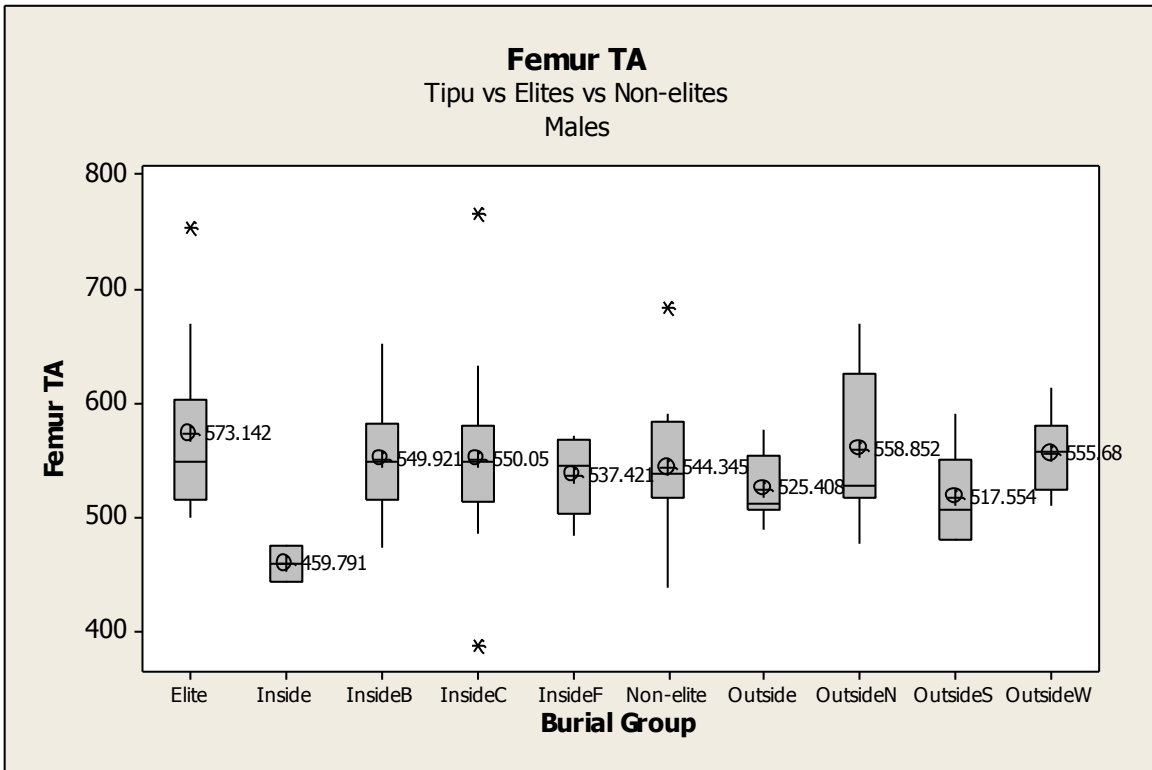
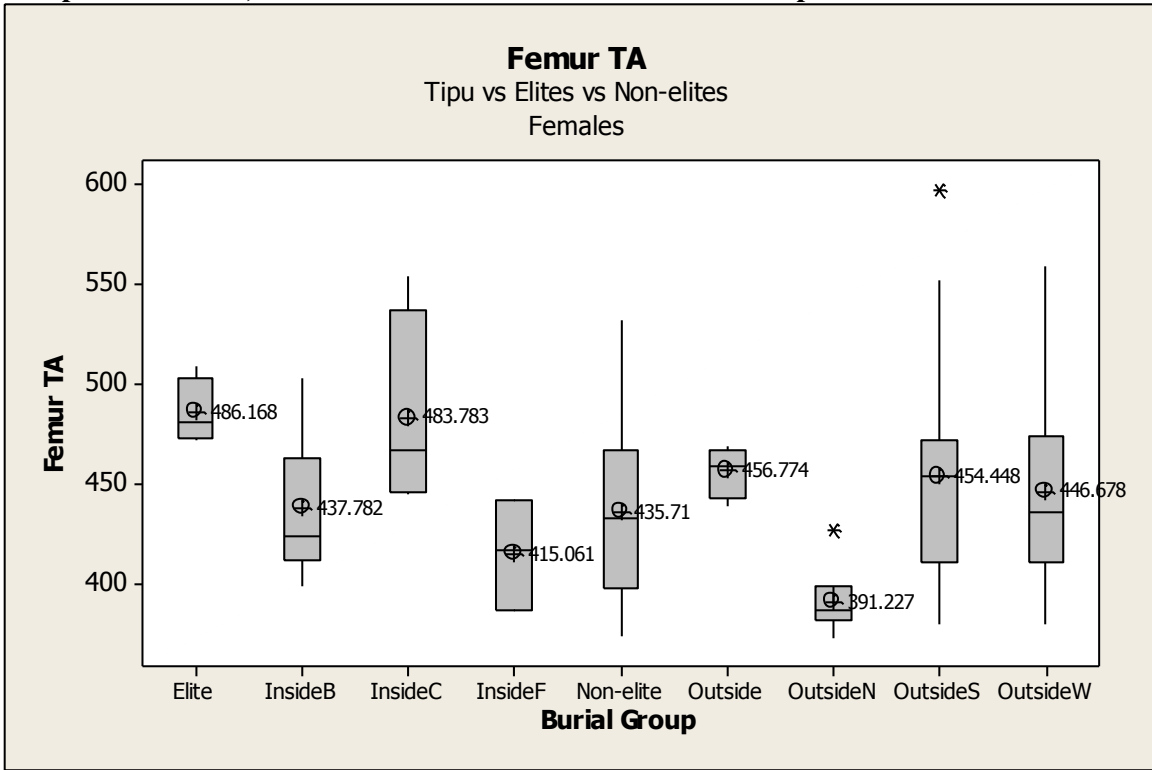
Box-plots of Femur, Tibia and Humerus *I_{max}/I_{min}* for all Burial Groups

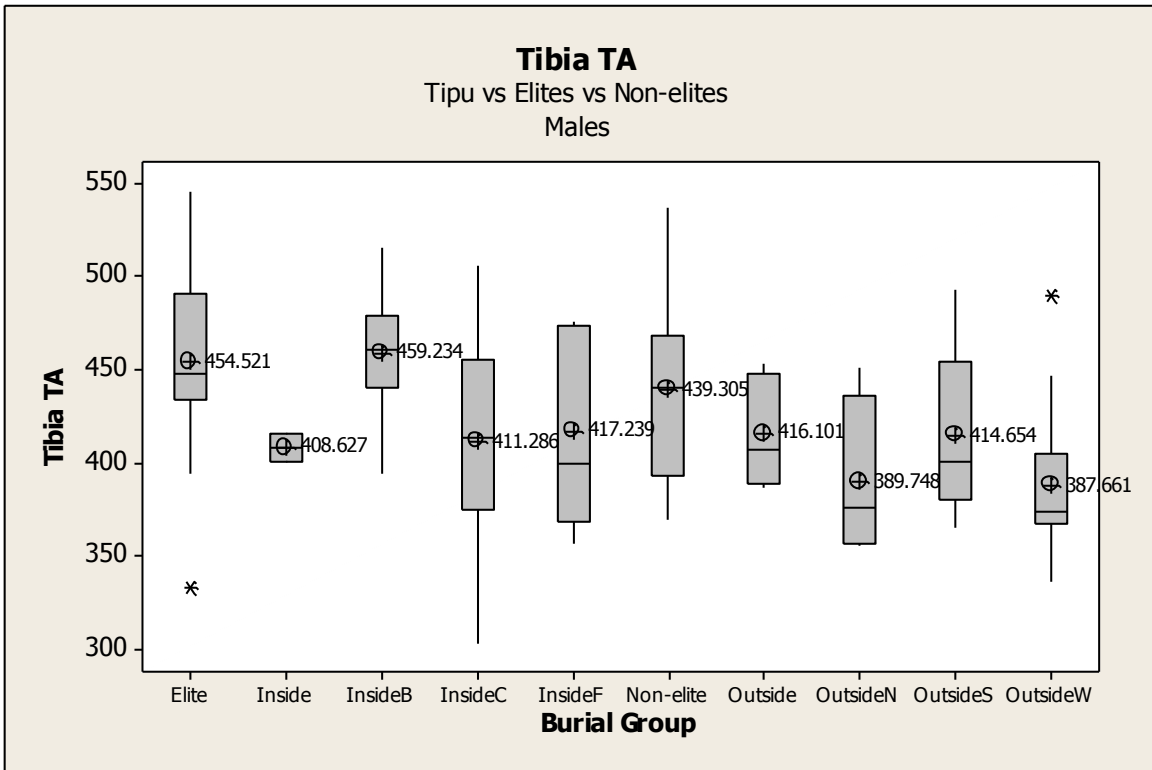
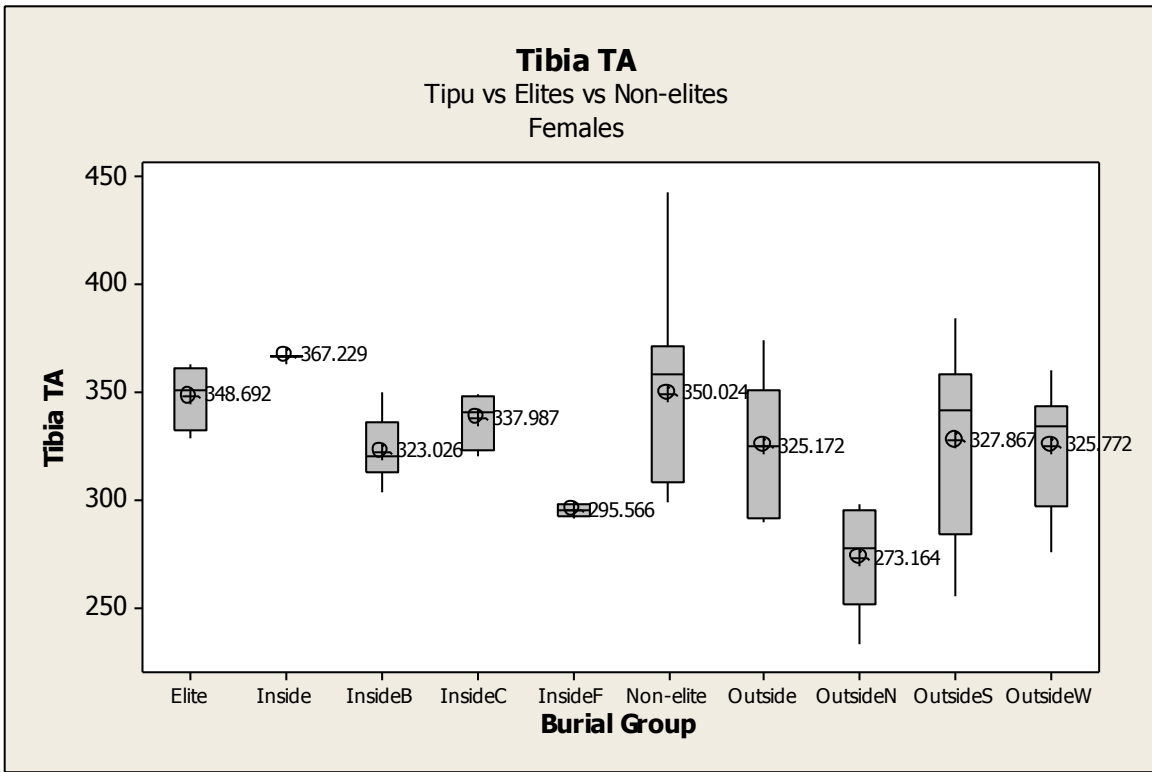


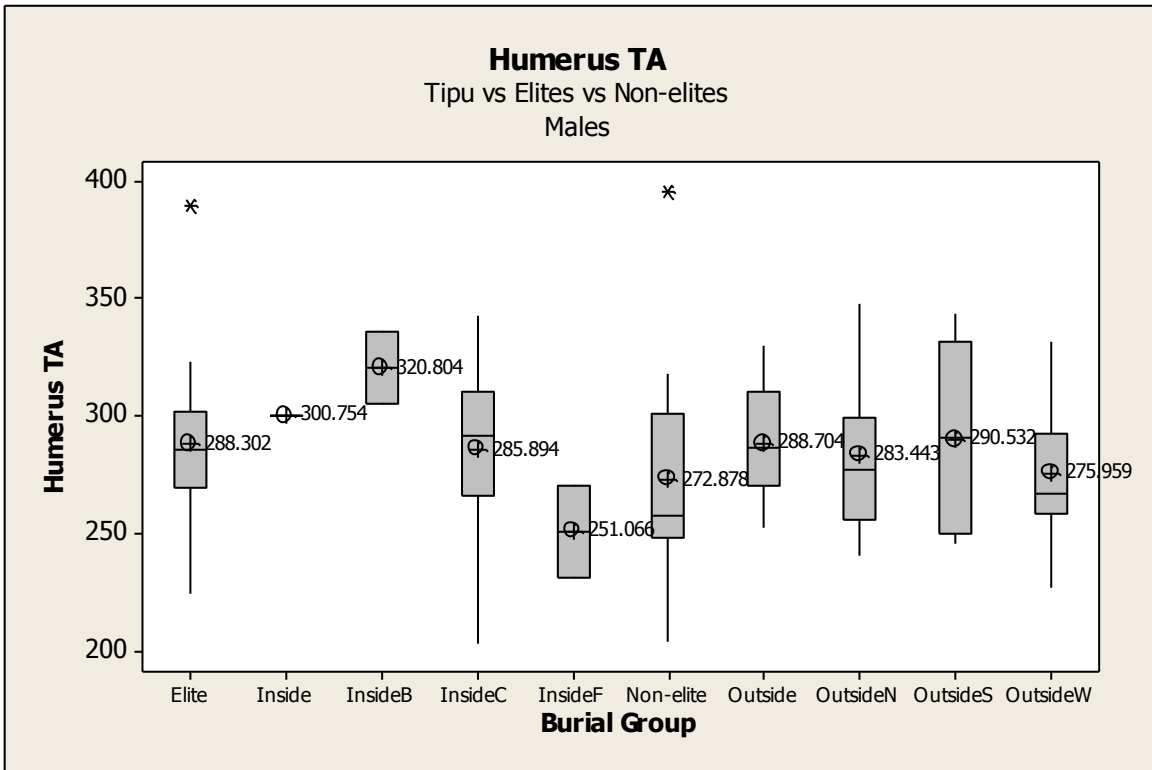
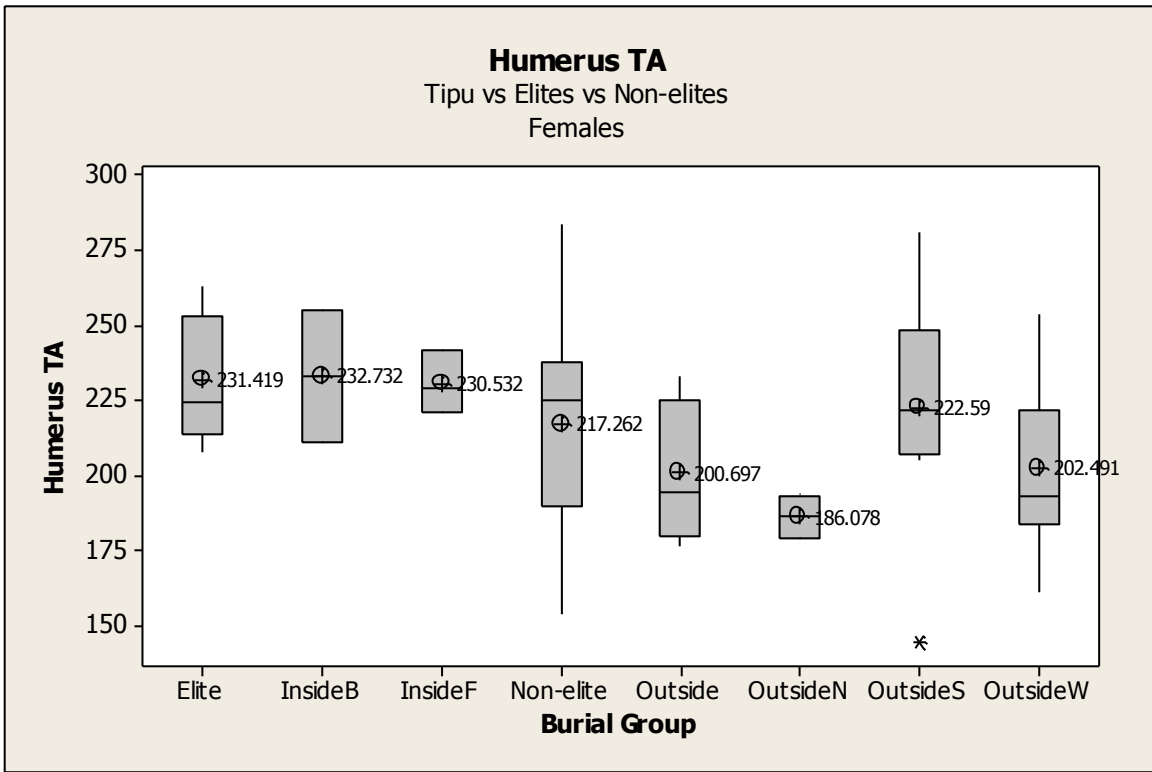




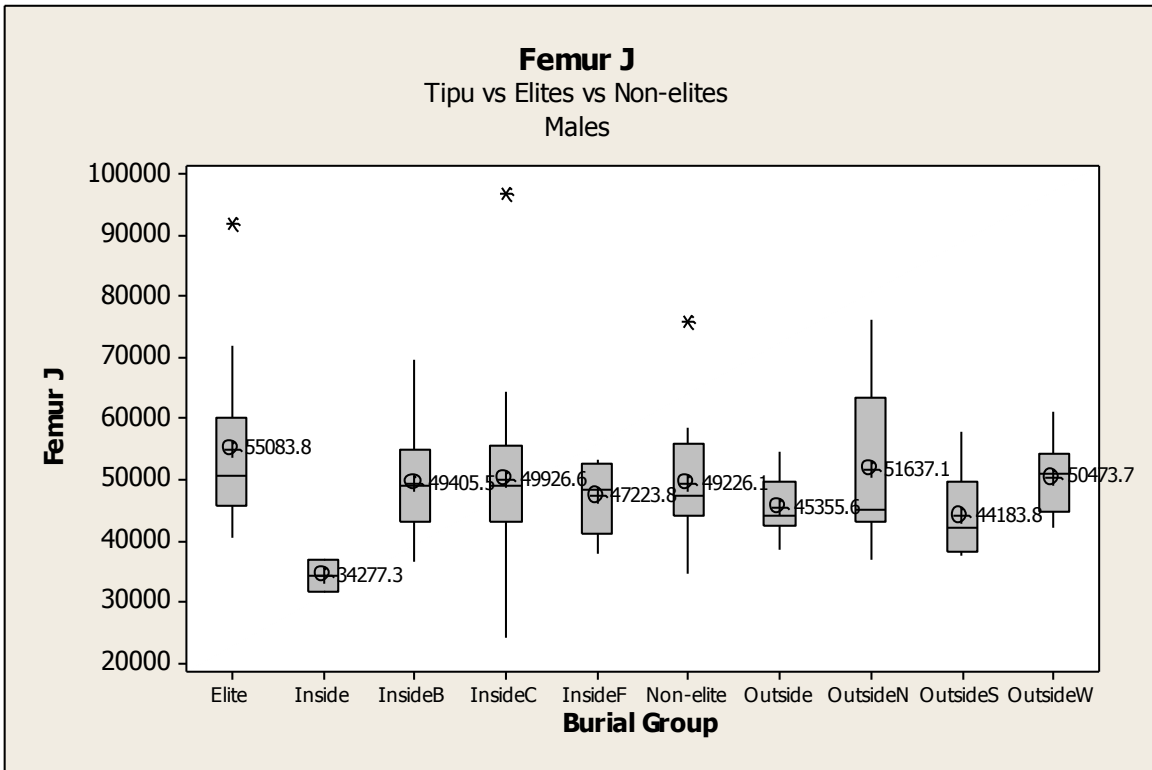
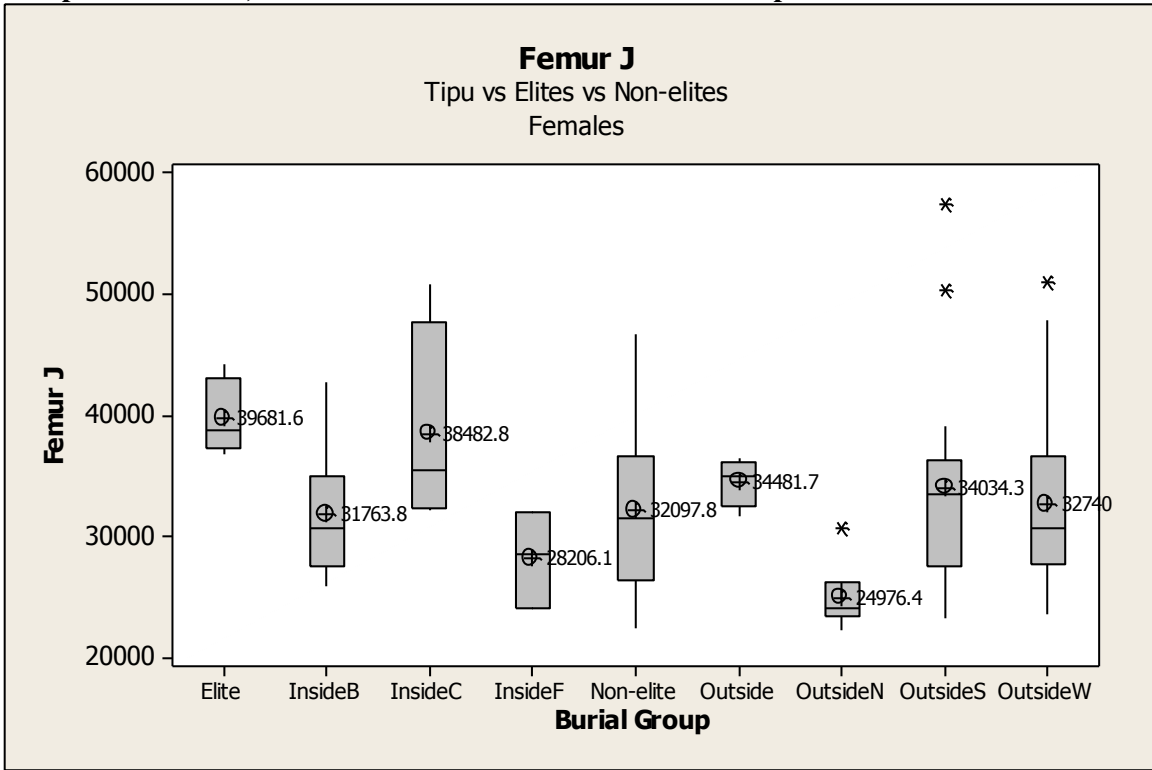
Box-plots of Femur, Tibia and Humerus TA for all Burial Groups

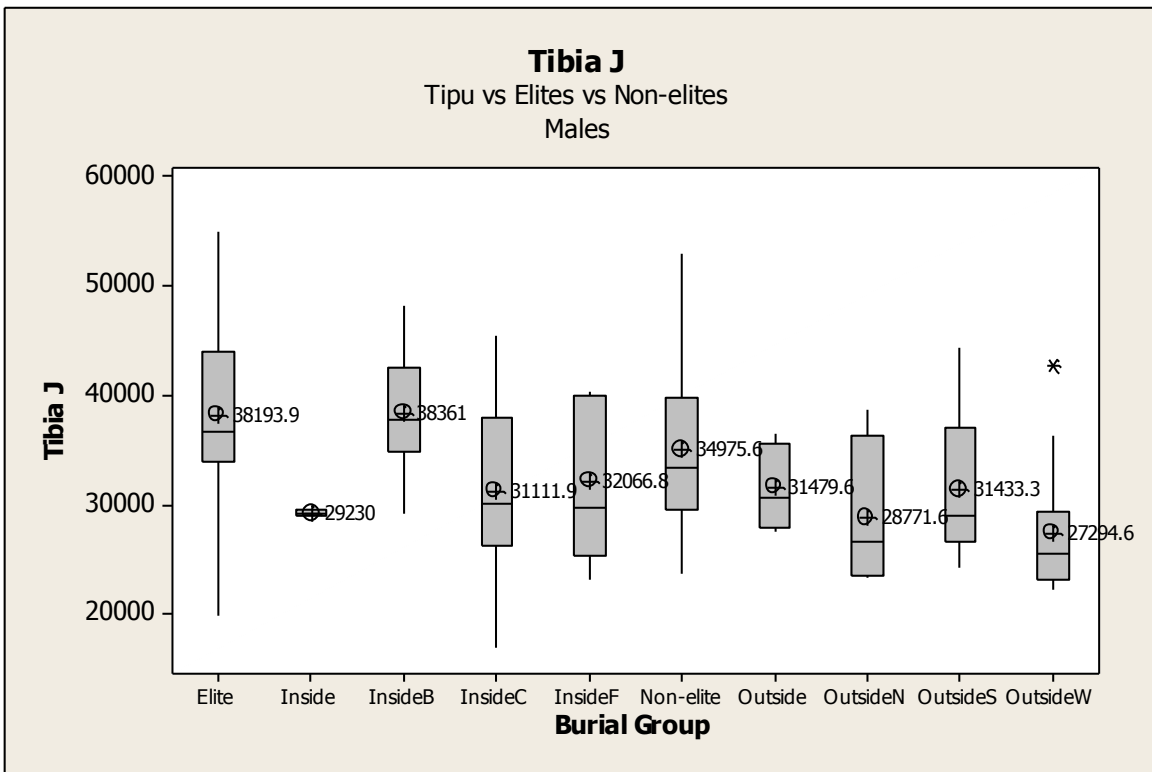
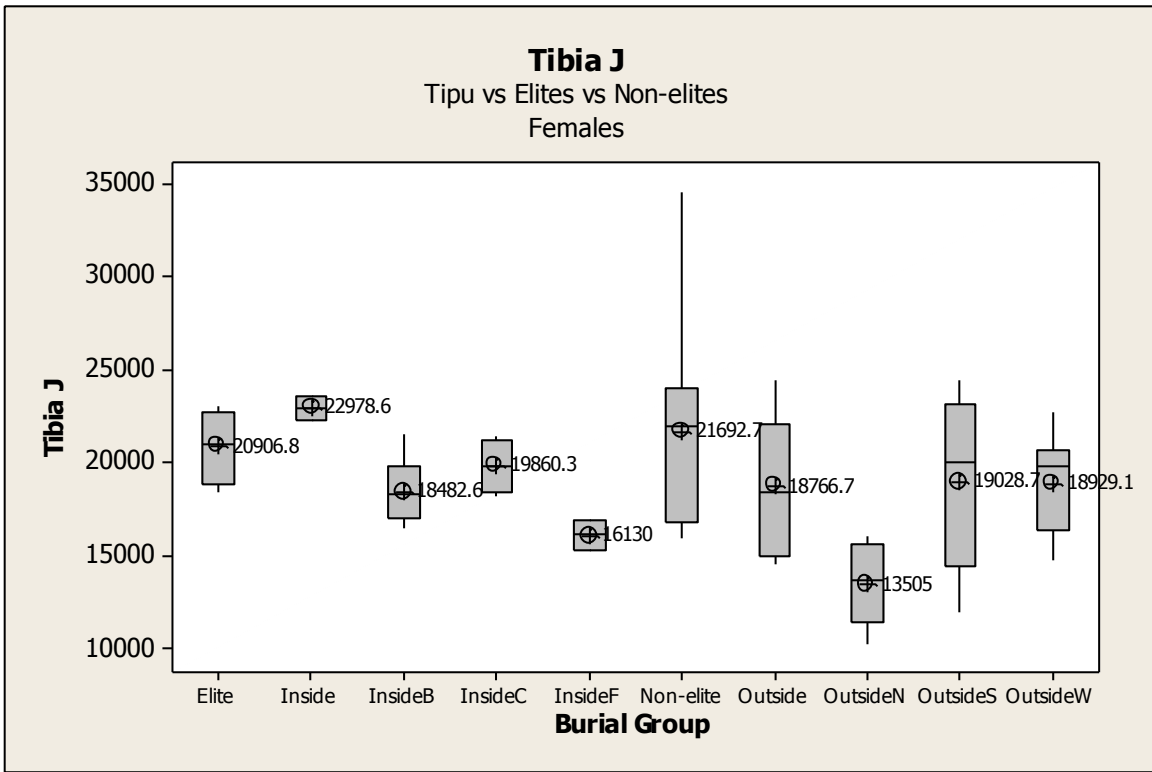


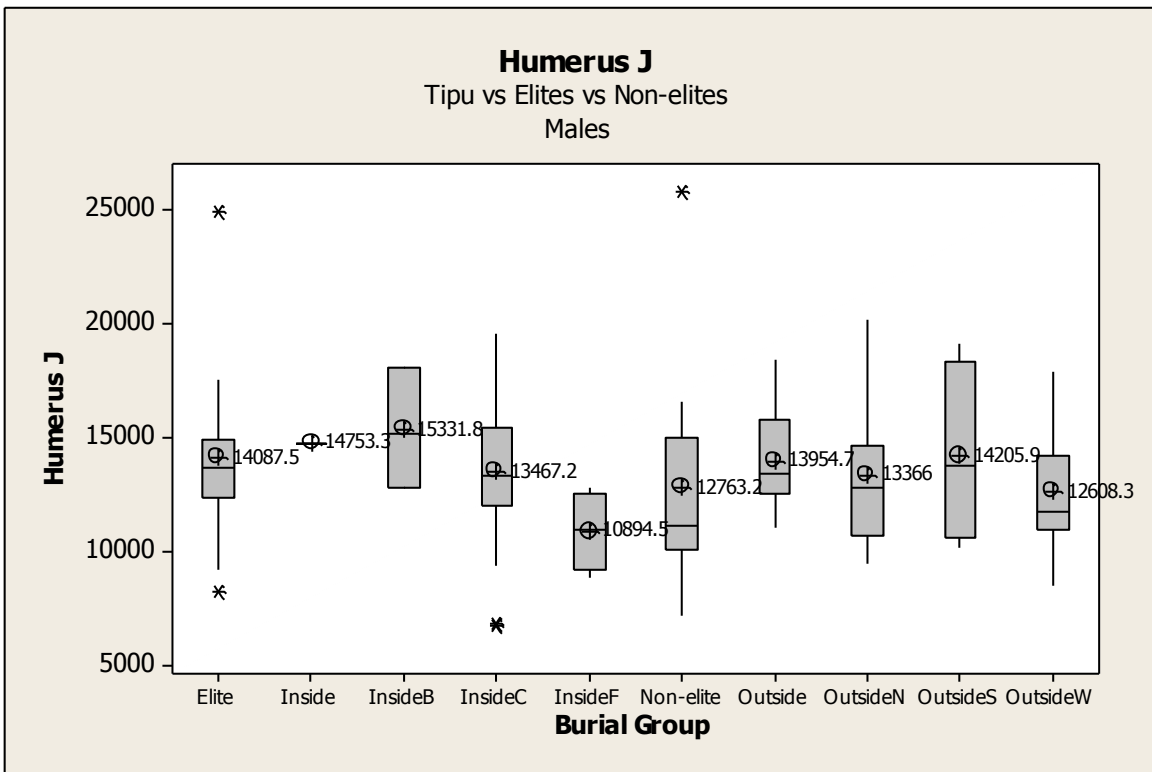
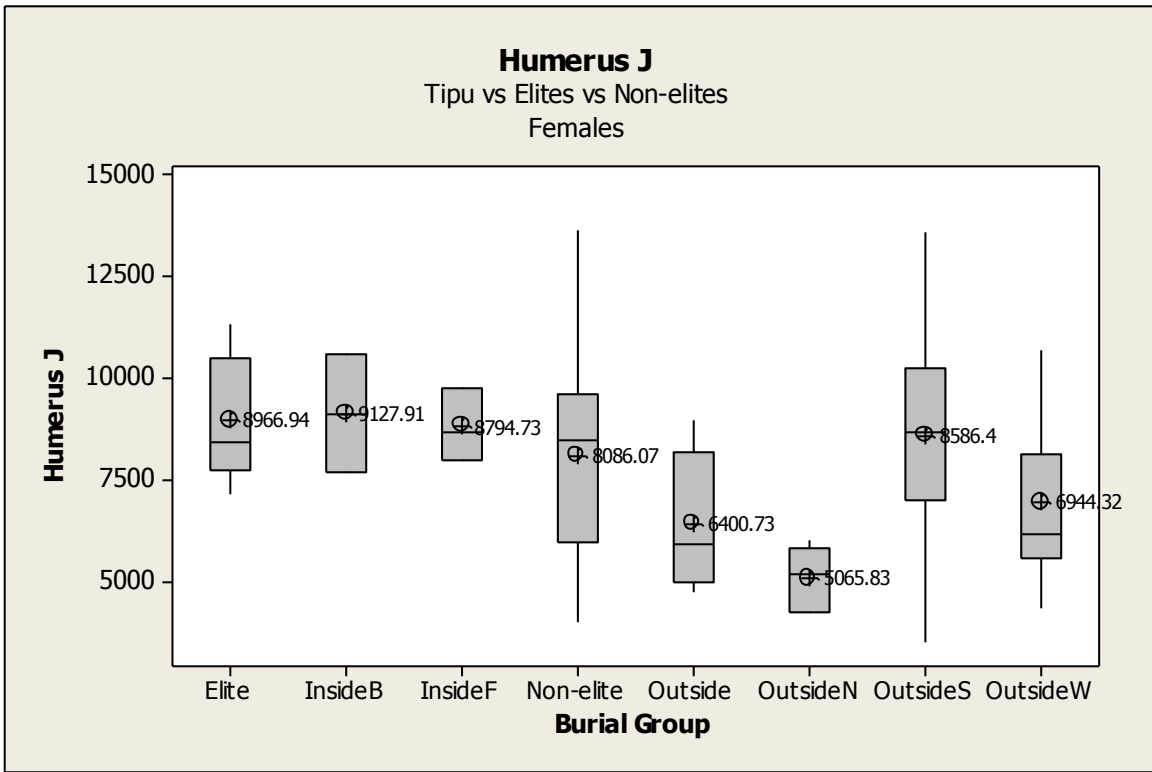




Box-plots of Femur, Tibia and Humerus J for all Burial Groups







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