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Porotic Hyperostosis and Cribra Orbitalia in the Adult Population of Tipu

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POROTIC HYPEROSTOSIS AND CRIBRA ORBITALIA
IN THE ADULT POPULATION OF TIPU

by

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ABSTRACT

Tipu is a contact period Maya site in western Belize where a mission church and cemetery was established around AD 1560. An archaeological excavation in the 1980s recovered the remains of more than 550 individuals. In its unique location on the fringes of Spanish control, Tipu was the site of both acceptance of introduced cultural traits as well as rebellion against them. The series has been intensively studied over the last decades, but an analysis of anemia using more recently developed and widely accepted standards has not yet been completed. Therefore, I scored adults using the new widely accepted standards in order to better understand the health of those at Tipu and the impact of colonization on the site.

Some 81 adults were evaluated for porotic hyperostosis, and 60 individuals scored for cribra orbitalia focusing on differences by sex, age and sex interaction, and status by proxy of burial location. Overall, rates of the conditions were intermediate compared to those at other Maya sites. Younger adults had high, but still moderate rates of porotic hyperostosis and cribra orbitalia, males had higher rates of porotic hyperostosis than females, and young males had the highest rates of all subgroups. However, there was no discernible status by burial location. This study supports other evaluations of health at the site that Tipu has moderate rates of porotic hyperostosis and cribra orbitalia and the population was relatively healthy despite Spanish colonization.

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DEDICATION

First and foremost, I want to thank my husband, Brandon Cubley. Without him I would not be where I am now. I would also like to mention my son, Harry, whose presence drove me to be the best mom I could be by completing my master's degree. Harry and Brandon are my biggest supporters, and I am so thankful for them. I would like to thank my mother for always being there when I need her. Finally, I would like to thank my first dog, Murphy. The joy he brought me in the early days of my degree helped me tremendously.

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LIST OF ABBREVIATIONS

CO	Cribra orbitalia
DOHaD	Developmental Origins of Health and Disease
PH	Porotic hyperostosis
RBC	Red blood cells
SUNY	The State University of New York

CHAPTER I - INTRODUCTION

Tipu is a Maya site located in west central Belize on the Mopan River that was occupied from the late Preclassic until their removal by Spanish colonial forces around 1707 (Graham 2011, 195). However, it had a particularly compelling existence during the early contact period when a Catholic mission church was established there in the 1560s. At the time, Tipu was situated on the frontier of Spanish control, which allowed its inhabitants to negotiate their relationship with the invaders in ways not possible in other parts of the larger region. The site served as a center for Maya fleeing more direct European control to the north in the Maya Mountains and into Yucatan (Graham et al. 1989, 1255-1258; Oland and Palka 2016, 474; Trask 2018). It also was a center of rebellion against Spanish efforts to take over the Peten region to the west, even having burned the church at one point during occupation (Graham 2011). These circumstances saw Tipu's population grew nearly tenfold in a single decade alone in the mid-1600s (Graham 2011, Jones et al. 1986), which inevitably had a myriad of effects on those who resided there. Thus, their experience with Spanish colonialism is arguably unique among the contact Maya people.

In the 1980s, archaeological excavations uncovered 588 historic burials in and around the mission church. Surprisingly, the overall health at Tipu does not appear to be as severe as other Maya populations at the time according to a number of health markers (Cohen et al. 1994) Among the conditions evaluated were porotic hyperostosis (PH), which are porous lesions that occur on the cranial vault bones, specifically the parietals, and cribra orbitalia (CO) which are porosities that occur the superior orbits of the frontal bones (Cohen et al. 1994, 130). PH and CO have most commonly been tied to various forms of anemia; however CO is also associated with scurvy (Walker et al. 2009). Tipu was observed for patterns of PH and CO over thirty years ago, but the analysis was undertaken by multiple observers and recorded only presence/absence of lesions. Since then, new, more widely accepted scoring standards for these conditions noting more nuanced aspects of the porosities have been published (Buikstra and Ubelaker 1994). Given that PH and CO are some of the most valuable indicators of childhood nutritional stress, evaluation of the series using these newer scoring standards potentially might reveal new insights concerning health at Tipu as well as provide more comparability to findings for patterns seen in other populations.

Therefore, I used the newer standards to score adults buried at Tipu in order to get a revised perspective concerning the rates of PH and CO at Tipu, especially as they might compare by population subgroup. In light of previous studies at Tipu and the companion site of Lamanai (need citation) finding low rates of PH and CO as well as the moderate rate of other pathologies found at Tipu, I hypothesized that this study would observe moderate rates of PH and CO at Tipu and that most lesions would be mild. I also hypothesized that younger adults would have higher rates of PH and CO due to the Developmental Origins of Adult Disease Hypothesis which states those who experienced adverse health early in life are more susceptible to adverse health and have a higher mortality rate later in life; furthermore, older individuals would have had a greater opportunity for remodeling to occur, which may have led to the obliteration of PH and CO porosities. Additionally, I anticipated sex differences would be present. Previous studies at Tipu have found that males have higher rates of health disruption than their female counterparts which led me to hypothesize that females would also better insulated due to genetic and physiological factors when it comes to PH and CO. Finally, I hypothesized that differences by status would have affected frequencies of the conditions. Using burial location in the cemetery as a proxy for status, those buried at the front of the church would be expected to more often be elite according to traditions of the time (Jacobi 2000), and thus be better insulated against PH and CO.

I then considered the physiological and cultural implications of these findings and contextualized them in comparison with other Maya sites over time and space in order to shed light on the lifeways of those residing at Tipu, both in terms of continuity with previous cultures as well as in light of response to Spanish contact. I identified patterns based on not only biological factors, but ones associated with cultural and ecological conditions as well.

This study is important because no investigation thus far has focused on the scoring of PH and CO at Tipu by a single observer using the most widely accepted standard interpreting the causes of these important indicators of childhood health. This study allows for a better understanding of the impacts, nutritional and otherwise, that the Spanish had on the fringes of conquest as the inhabitants of the site accommodated tremendous culture change as they maintained still maintained so many cultural traditions of their ancestors.

CHAPTER II - THE SITE OF TIPU

This chapter discusses the history of Tipu and its unique position as it relates to Spanish colonization. I give an in-depth review of the site from the time of contact to the removal of the population of Tipu. Also addressed is the Christian church at Tipu and how the individuals at Tipu buried their dead. Furthermore, I address the diet of the Maya in general and their dependence on maize, how the Maya diet has changed throughout time, and how colonization may have impacted diet. I then discuss the overall health of those at Tipu based on previous studies involving the population. Finally, I give an overview of the previous study of PH and CO completed using Tipu and how the data might change with the introduction of new widely accepted standards.

The Maya site of Tipu, located on the west bank of the Macal branch of the Belize River, was the political center of the Dzuluinicob province (Jones et al. 1986) (Figure 2.1). Its earliest occupation dates to the Preclassic period (1000 BC – AD 250), and it was still occupied when Europeans arrived. Initial Spanish contact in Belize occurred in 1528, and Maya peoples in northern Belize were especially subjected to intense colonization (Graham et al. 1989). At that time, the Maya already had an economy involving both land and sea, an advanced calendrical system, a writing system, elaborate religion and religious practices, and a stratified social system including rulers, priests, scribes, warriors, craftworkers, traders, farmers, and fishermen (Graham et al. 1989). The Spanish, however, systematically worked to colonize the area as they forced their own cultural norms and practices on populations across Belize including introducing and encouraging the practice of Christianity among Maya groups.

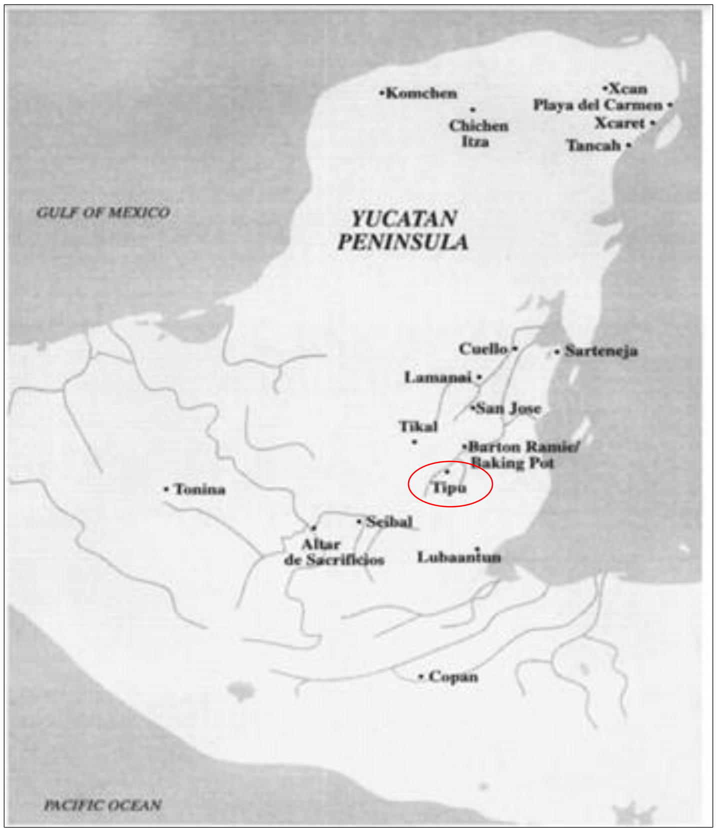

Figure 2.1 *Map of Maya sites in the Southern Yucatan featuring Tipu (Danforth et al. 1997, 14)*

Around 1542, the Spanish reached Tipu and the surrounding region, which was nominally "conquered" by Spanish cousins Alonso and Melchor Pacheco (Jones et al. 1986: 40). However, they held loose political control at best over the Maya groups due to the fact that the population was highly dispersed. Around 1547, the Maya around Tipu instigated a rebellion against the Spanish by killing a Spaniard who oversaw security and religious conversion; this act gave rise to further conflict in the region between the Spanish and Maya (Jones et al. 1986, 41).

Nearly three decades after the Pacheco cousins began their control and two decades after the rebellion began, Juan Garzon reconquered the Maya region in about 1567 (Jones et al. 1986: 41). Some Maya groups were required to give tribute crops to the

Spanish, although there is no evidence of this at Tipu, which is likely due to its location on the fringes of colonization (Graham et al. 1989). Due to this location, the cultural and economic disruption caused by contact may have helped keep Tipu somewhat better insulated from nutritional and other health stresses compared to Lamanai and other sites closer to the coast. However, they still would have potentially been exposed to diseases brought over by the Spanish (Graham 2011).

2.1 The Community of Tipu

Under Spanish control, as tenuous as it often might have been, the site of Tipu underwent a physical reorganization, and a church and other buildings were built and centered around a European style plaza (Graham 2011) (Figure 2.2). The church was one of a series of 19 missions based out of Bacalar, which was located just over the now northern border of Belize with Mexico (Jones et al. 1986; Graham 2011). The churches extended to the southwest with Tipu being the last in the chain. The missions did not have resident priests, but rather were serviced on a sporadic basis by Franciscans who would occasionally travel the circuit (Jones 1989). Despite only occasional presence of the Spanish, the missions appear to have been one introduced cultural institution that thrived. We know the Maya at Tipu maintained traditionally Christian burial practices and they also maintained the church for the next 60 years (Graham 2011).

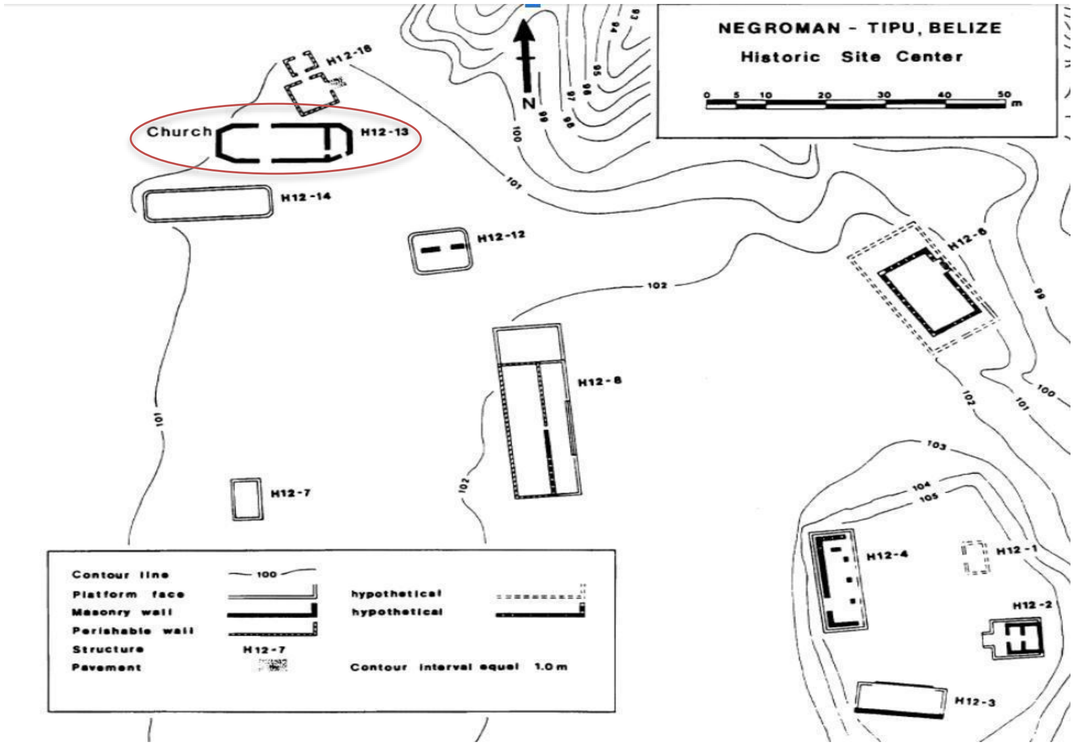

Figure 2.2 *Site map of Tipu during Historic Period.*

In an attempt to further pacify the inhabitants of Tipu, the Spanish introduced apostate Maya from remote villages to settle at the site in order to resettle and regrow the community in a way that favors the Spanish, though this does not seem to have an impact on Maya ways or culture at Tipu (Graham et al. 1989). However, unrest associated with colonization efforts continued. In 1638 there was a widespread rebellion, and the Spanish were expelled from much of Belize, including Tipu (Graham et al. 1989). In 1641 it became the center for the revolt with even the apostate Maya joining the effort (Graham et al. 1989). Additional Maya from the Yucatan and northern Belize fled to Tipu to seek refuge from areas that were under more direct Spanish control, in part because of its location as well as historic connections with the Itzá to the west (Cohen et al. 1994, 122 and Trask 2018). This influx of migrants to Tipu caused a large population increase with the number of residents rising from 100 to over 1000 in just a decade (Jones et al. 1986).

2.2 The Mission Church

While the inhabitants of Tipu at times rebelled against the Spanish, it does not appear that they rejected Christianity based on the maintenance and use of the church. The church, like many colonial churches in Yucatan, faced west and was located at the northern end of the plaza (Jones et al. 1986, 41). In a series of excavations in the 1980s under the direction of Mark Cohen from SUNY-Plattsburgh and Elizabeth Graham from the Royal Ontario Museum, burials were found both in the church nave as well as in the graveyard around the church, but were most densely packed in the nave, as seen in Figure 2.3. Out of the nearly 600 burials recovered, 588 were from the historic contact period (Cohen et al. 1994).

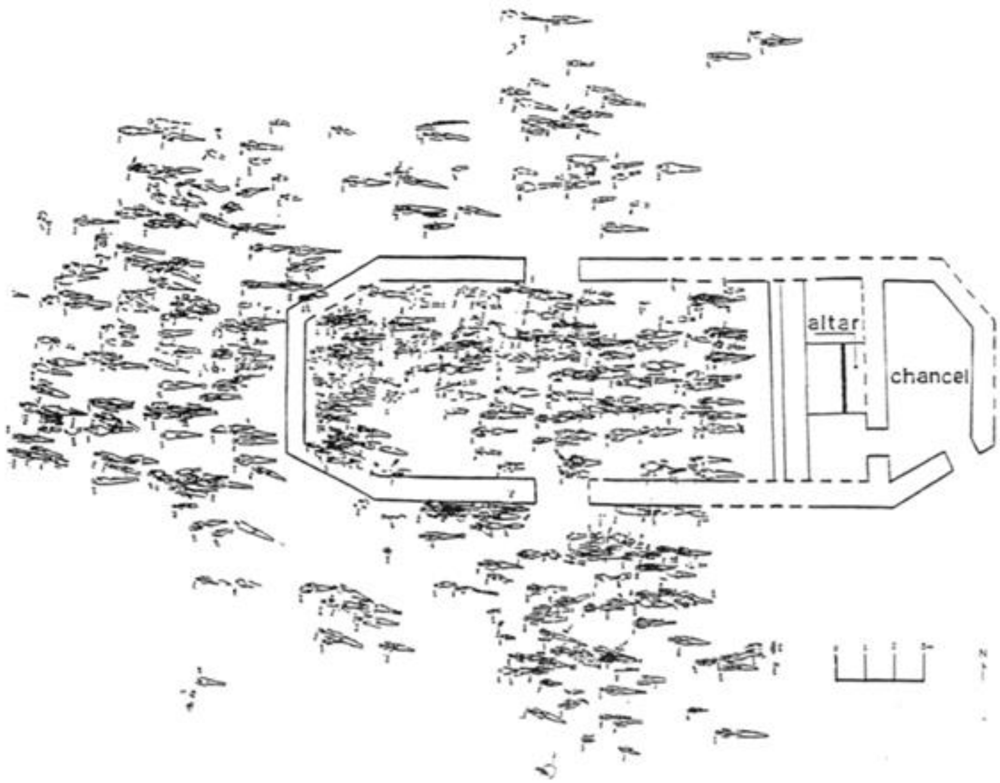

Figure 2.3 *Location of burials in and around the church at Tipu (Danforth et al. 1997, 15)*

Nearly all were buried in Christian style as single primary burials with heads to the west and with few, if any, grave goods. Most of these individuals were buried in shrouds as indicated by the recovery of shroud pins in the interments (Cohen et al. 1994). One older male adult, who was buried at the front and center of the nave of the church, was buried in a coffin (Cohen et al. 1994). It is possible that individuals were interred in separate family plots as evidenced by the occasional presence of clusters of discrete dental traits (Cohen et al. 1994). Jacobi (2000) found that it is unlikely that there was any European admixture to the population as indicated by the presence of shovel-shaped incisors, which are indicative of Native American ancestry. Other researchers working with mitochondrial DNA (mDNA) found no evidence of admixture at Tipu as well (Elwess et al. 2015).

2.3 Lifeways at Tipu

Regardless of the Spanish influence and colonialism, archaeological excavation at Tipu has indicated that its inhabitants largely continued to follow their traditional Maya lifeways until their removal to the shores of Lake Peten in 1707 (Graham et al. 1989). Most portable objects, such as ceramics, were still fashioned in Maya styles with the integration of some Spanish items, such as glass beads and items used in church services (Graham et al. 1989). It is likely that Spanish artifacts found at the site were obtained through trade with other Maya sites and did not reflect direct trade with the Spanish colonizers (Jones et al. 1986). There is also no evidence of any long-term Spanish residents at Tipu (Jones et al. 1986).

The diet of Maya groups varies across individuals, sites, time periods, and socioeconomic status (Marcus 2003). The initial signs of agriculture in Belize were present around 3000 BC even before the occurrence of pottery or even villages (Marcus 2003). Artifacts from these sites include shell refuse, stone tools in a variety of sizes, cooking stones, post holes, and at times evidence of maize (Marcus 2003). Later, during the Preclassic, maize had already become a high-status food but constituted less than 50 percent of the overall diet (Marcus 2003). This was likely because small population sizes of this time allowed for more access to wild resources, such as low energy game such as deer and turtles (Marcus 2003). Furthermore, maize may have been cultivated primarily out of ease (Marcus 2003).

In the late Preclassic, wetlands were converted to raised fields and there is evidence of terraces, drained fields, arboriculture, and even canals, all of which were used to cultivate food and coincide with the shift from chiefdom to state (Marcus 2003). During this time we see an increase in the reliance on maize, now comprising more than 50 percent of the diet, which is likely due to the overexploitation of natural wild resources from higher population size and density (Marcus 2003). Elites were shown to have the greatest variability in their diet during this time as well in both floral and faunal/marine resources (Marcus 2003). During the Late Classic Collapse of the Maya around AD 900, there was a decrease in the reliance of maize which is again likely because the Maya populations were less dense and more dispersed who again were exploiting more local natural wild resources and accessing more environmental zones (Marcus 2003). Beans and squash were grown as well, making these three foods the trinity in the diet of the Maya (Whitlock 1976). In addition, evidence of cacao, sweet potato, vanilla, pojote, and zapote has also been found (Whitlock 1976).

While Tipu evidently did not have domesticated livestock (Emery 1999), there is evidence of animal remains at the site including birds, fish, deer, and turtles among others, and it is likely these protein sources were hunted (Marcus 2003, 78). These resources were especially likely sought out because their hunting low energy exertion; furthermore, they provided much needed nutrients that cultivated plants at the site did not provide such as iron and B12 which complemented the high rate of carbohydrates consumed through maize and squash (Marcus 2003, 78). However, even with these animal protein sources along with sources of plant protein such as beans in their diet, the high rate of carbohydrates from cultivated crops, most notably maize, left individuals at Tipu susceptible to various types of anemia.

2.4 The Downfall of Tipu

Beginning in the mid-1600s, Tipu was rather successful in maintaining its independence from Spanish control, continuing to serve as a center of rebellious efforts, coordinating efforts with Maya groups to the west (Graham et al. 1989; Graham 2011). The mission church was even reportedly burned at one point. However, leaders from Tipu in 1695 traveled to Merida to invite the Spanish to return to the center, who then complied. Within two years, the Peten Itzá were finally conquered. By 1707, the residents of Tipu were forcibly moved from their community to Lake Peten Itzá, bringing an end to a Maya center that had existed for nearly 2000 years (Graham 2011).

2.5 General Health Patterns of the Tipu Maya

Overall, the population at Tipu appears to be generally well insulated from trauma and various pathologies due to their location on the frontier from extensive contact with the Spanish. However, they did show presence of a number of health challenges, such as linear enamel hypoplasia, Wilson bands, caries, periosteal lesions due to inflammation, scurvy, and trauma (Bianchi 2020; Cohen et al. 1994, 1997; Danforth 1989, 1997; Gomberg 2018; Harvey 2011). Frequencies of linear enamel hypoplasia (LEH), which are growth disruptions in the teeth during formation most commonly caused by periods of nutritional stress, peaked in children around 2-3 years old and are most likely associated with weaning (Harvey 2011), a finding also supported by isotope analysis (Hiers 2014). Males at Tipu were found to have higher rates of hypoplasia than their female counterparts (Danforth et al. 1997, 17). Tipu's overall rate of LEH is similar to those at other Maya sites and falls close to the median range for the sites used comparatively shown in Table 2.1. Wilson bands, another non-specific microscopic enamel defect usually due to nutritional stress, were also studied at Tipu. Again, males were found to have significantly higher rates of Wilson bands than females at the site (Danforth 1989). Scurvy was also seen at Tipu and Gomberg (2018) noted that in general, the rates of scurvy at Tipu were moderate, but that males were more susceptible than females.

Table 2.1 *Population frequency of linear enamel hypoplasias across various Maya sites (Danforth et al. 1997, 17)*

Site	Males (n)	Females (n)	Source
Tipu – incisors	.73 (48)	.60 (43)	Cohen et al. 1994
Tipu – canines	.85 (56)	.85 (35)	Cohen et al. 1994
Tancah, Yucatan	.71 (7)	.00 (1)	Saul 1982
Cuello, Belize	.56 (39)	.6 (12)	Saul and Saul 1991
Altar de Sacrificios, Guatemala	.88 (24)	9)	Saul 1972
Lubaantun, Belize	7)	5)	Saul 1975
Barton Ramie, Belize	.76 (21)	1.00 (5)	Cohen et al. 1989

Overall, it is evident that females had lower rates of childhood health disruptions overall, a pattern seen in many other populations. Male infants in general have a higher mortality rate 1.44 times higher than that females at all ages (McFadden and Oxenham 2020, 212). This insulation results in the growth and development of males being more adversely affected than females in any given population, as is evident in the studies mentioned above (Grauer and Stuart-Macadam 1998, 3; Huss-Ashmore et al. 1982, 413).

These findings indicate that females either have are more robust against deficiencies, or males are more susceptible to these deficiencies leading to an early death (McFadden and Oxenham 2020, 212).While females have this innate buffering or robustness throughout most of their lives, during childbearing and lactation they may not be as insulated from nutritional stress due to the stress on the body of providing nutrition for a growing fetus and then a child upon birth. However, it appears that once pregnancy and lactation cease, females return to having some insulation from nutritional stress (Grauer and Stuart-Macadam 1998, 3; Huss-Ashmore et al. 1982, 413).

Health patterns during adulthood have also been addressed at Tipu. It was found that females had a higher rate of caries than males which means females were likely consuming more carbohydrates and males may have had more access to protein sources (Danforth et al. 1997, 18). When compared with other sites, the rates of caries at Tipu were quite similar (Danforth et al. 1997, 18) (Table 2.2}, although the sex differences are not as notable.

Table 2.2 *Comparable data showing the rate of caries by individual at various Maya sites including Tipu (Danforth et al. 1997, 18)*

Site	Males (n)	Females (n)	Source
Tipu, Belize	.71 (59)	.92 (47)	Cohen et al. 1994
Tancah, Yucatan	1.00 (3)	1.00 (1)	Saul 1982
Cuello, Belize	.86 (36)	1.00 (8)	Saul and Saul 1991
Altar de Sacrificios, Guatemala	.86 (22)	.89 (9)	Saul 1972
Sarteneja, Belize	.75 (4)	.00 (2)	Kennedy 1983
Lubaantun, Belize	.60 (5)	.67 (6)	Saul 1975

Periosteal lesions due to inflammation were evaluated at Tipu as well, and it was found that females had lower rates than males, which could indicate that males were more susceptible to injury while hunting or working in the fields (Armstrong, 1989). Researchers also have observed a lower rate of trauma than can be found at other Maya sites that were under more direct Spanish control, likely related to Tipu's location on the Spanish frontier (Cohen et al. 1994). At Tipu, males had higher rates of trauma than females; however, the difference was not found to be statistically significant (Cohen et al. 1994).

In the 1980s, several laboratory workers evaluated health markers assumed to be associated with anemia in the Tipu population. Based on understandings at the time, it was presumed that the cause of any anemia seen was related to the maize-based diet of the Maya (Najjar et al. 1976). Males were found to have significantly higher rates of the associated pathologies than their female counterparts; however overall, Tipu had lower rates of these pathologies when compared with other Maya sites (Cohen et al. 1994 and Danforth et al. 1997, 17). These results, however, must be viewed in the context that the lesions were scored before a standard scoring scale was introduced and widely applied in the field of paleopathology (Buikstra and Ubelaker 1994), so some of the differences may simply be related to interobserver differences in anemia evaluation among researchers). Furthermore, iron deficiency anemia more recently has been ruled out as the only cause of porosities of the crania (Walker et al. 2009). Therefore, the lesions are re-evaluated in the present study and an expanded discussion concerning their causes and scoring is given in the following section.

The health of Tipu is relatively good and those at Tipu were better insulated against nutritional stress when compared to Maya sites. This is likely due to the insulation from the Spanish due to being on the fringes of conquest. Health markers also indicate that males had more markers of nutritional stress, and they may not have been as insulated from nutritional stress as their female counterparts. Although all these data give us a good idea what health may have looked like at Tipu, there has not been aa consistent correlation between health and status using burial location as a proxy. This may mean that burial location did not reflect status as would be anticipated based on Catholic traditions (Jacobi 2000), or it may indicate that status did not allow for advantages resulting in better health at Tipu. PH and CO were also studied at Tipu, but due to new standards PH and CO need to be re-evaluated in order to better contextualize the rates at Tipu with other Maya sites throughout time and space, which this study aims to do.

CHAPTER III - POROTIC HYPEROSTOSIS AND CRIBRA ORBITALIA IN ANCIENT POPULATIONS

3.1 Anemia and Its Causes

Porosities occurring on the skull are among the most frequently reported lesion in archaeological populations. Many potential causes for their presence are possible, including certain genetic conditions, such as thalassemia major and sicklemia, more commonly known as sickle cell anemia, but they cannot account for the high rates of porotic lesions that we see in most ancient groups (Walker et al. 2009, 110). Thalassemia and sicklemia are rare and population-specific; both types of anemia are evolutionary responses to malaria and are associated with the Old World. Therefore, these anemias cannot account for the high prevalence of PH and CO in Indigenous populations in the Americas (Brickley 2018, 896; Walker et al. 2009, 109).

In the 1940s, Hooton was one of the first researchers to observe these porous lesions in the precontact Maya, namely in the population from Late Classic Chichen Itzá in Yucatan. He attributed them to a nutritional deficiency due to a maize dependent diet; however, he did not go as far as to specify what deficiency he thought caused these pathologies (Wright and Chew 1998, 926). In the early 1970s, there was a rise in the consensus that the porosities, now referred to as porotic hyperostosis (PH), when on the skull vault and cribra orbitalia (CO) when on the orbital roofs, were the result of anemia, specifically iron deficiency anemia (Wright and Chew 1998, 926), the nutritional shortcomings of a maize-based diet being responsible. However, in recent years even this interpretation has undergone revision.

Anemia is a group of pathological symptoms due to deficiency of red blood cells (RBCs) or hemoglobin, a key component of RBCs, but it is not a specific disease (Walker et al. 2009, 110). The condition is defined as having hemoglobin levels below an established cut-off or threshold and is indicative of insufficient hemoglobin or red blood cells resulting in a deficiency of oxygen (Brickley 2018, 897). Anemia can be caused by a variety of factors including blood loss, RBC destruction (increased hemolysis), and/or impaired erythropoiesis (Walker et al. 2009, 110). The most common form of the condition is iron deficiency anemia (Walker et al. 2009, 111).

Based on modern clinical cases with radiographic and hematological evidence, iron deficiency and cranial vault marrow hypertrophy associated with PH and CO for many years has been thought to co-occur; however, these radiographic studies did not account for other possible hemolytic processes or diseases in addition to iron deficiency anemia (Walker et al. 2009, 109; Rothschild 2000, 86). Iron deficiency anemia results from an iron deficient diet and/or malabsorption of iron, and therefore researchers believed this to be the cause of a high prevalence of porotic lesions on the cranium among ancient populations where maize was the staple crop (Holland and O'Brien 1997, 183). From more recent clinical studies, however, we have learned that iron deficiency anemia causes a decreased mature RBC production which would not cause hypertrophy of the marrow to the extent that we see leading to porotic lesions in the orbits or cranial vaults associated with PH and CO (Walker et al. 2009, 112). In fact, when considering various other hemolytic responses, less than 1% of cases of porous cranial lesions are attributed solely to iron deficiency anemia (Rothschild 2000, 86).

Consequently, researchers have shifted away from iron deficiency anemia being the primary cause of porosities related to these pathologies. They have found that megaloblastic anemia results in premature destruction of RBCs, which then causes the red marrow to overproduce RBCs to compensate for the loss which in turn causes marrow hypertrophy (Walker et al. 2009, 110 and 112). This overproduction of RBCs caused by megaloblastic anemia can lead to the pathological symptoms seen in the cranium relative to PH and CO. These anemias are the result of vitamin B12 and/or folic acid deficiency and are likely to co-occur with other deficiencies (Walker et al. 2009, 112). Although a vitamin B12 deficiency can be due to other causes such as digestive problems, parasites, and/or lack of metabolic absorption, it is usually the result of a lack of meat and meat byproducts, with some mushrooms containing a small amount of B12. However, megaloblastic anemia could also be due to a folic acid deficiency or a deficiency in both B12 and folic acid. Folic acid can be found in a variety of foods including beans, leafy green vegetables, whole grains, and seafood. It is difficult to ascertain if megaloblastic anemia is a result of vitamin B12 deficiency on its own or folic acid deficiency.

In addition to nutritional deficiencies resulting from the diet, anemia in all forms can be brought on by various other vectors including gastrointestinal infections or parasites and consequent nutrient loss (Holland and O'Brien 1997; Walker et al. 2009, 114-115). While some causes may be that an individual has a metabolic disorder that does not allow for the complete absorption or distribution of some nutrients, other causes can be attributed to external factors. Some of these may have cultural implications; for instance, anemia can be indicative of famine and/or unsanitary living conditions which then cause diarrheal disease and thus inhibit the uptake of necessary nutrients from the diet. Unsanitary living conditions can also lead to a higher rate of diarrheal disease and/or the introduction of parasites. Various parasites may exacerbate prior deficiencies, although some have argued that parasites can cause significant deficiencies on their own (Holland and O'Brien 1997, 191).

There is also the possibility that a child in utero may suffer from anemia due to maternal deficiencies during pregnancy and the possibility of a lack of vitamins being transferred during breastfeeding after birth. Prior to prenatal vitamins, women depended entirely on the foods they consumed to not only get enough vitamins to support themselves, but to also get enough to support a growing fetus. Anemia that is passed down by the mother due to insufficiencies in nutrients during pregnancy and/or nursing may cause a more exaggerated form of anemia in the infant (Walker et al. 2009, 115). Those who suffered adverse nutrition during gestation and early childhood also appear to be more susceptible to disease as adults (Barker et al. 1989; Barker 2002). Weaning can also cause gastrointestinal stress due to the introduction of various foods that the digestive system is not accustomed to causing diarrheal disease which can cause anemia to become more severe, so if an infant is already anemic due to nursing and/or in utero deficiencies, weaning could exaggerate this anemia further (Walker et al. 2009, 115).

Anemia has the capability of co-occurring with other illnesses and deficiencies such as scurvy or autoimmune diseases which may in turn exacerbate the anemia or could cause anemia on their own. Studying these pathologies and their possible causes, both internal from individual to individual as well as the possible cultural or external causes, helps us better understand their implications such as socioeconomic status of various individuals or groups as well as the overall health of the population.

3.2 Porotic Hyperostosis and Cribra Orbitalia

Both conditions result in macroscopic pitting and porosity as well as the possibility of bone thickening in the superior eye orbits for CO and on the cranial vault for PH (Walker et al. 2009, 109). PH and CO have been found to be caused by the hypertrophy, or expansion, of the body's red marrow which is the site of the production sites of red blood cells (RBCs) for the body (Brickley 2018, 899; Walker et al. 2009, 109). Porosities associated with PH on the parietals can be seen in figure 3.1 below, whereas porosities associated with CO are shown in figure 3.2.

Figure 3.1 *PH score of 1 in individual at Tipu (MT 366)*

Figure 3.2 *CO score of 1 in individual at Tipu (MT 527).*

Researchers initially thought CO was a precursor to PH on the cranial vault (Brickley 2018, 899). This was presumed since the bone of the superior orbits is very thin, so less hypertrophy of the red marrow is needed to cause porous lesions whereas porosity of the cranial vault requires more hypertrophy to appear due to the greater thickness of the bone. Thus, it was assumed that only in the more moderate to severe cases were both PH and CO present (Walker et al. 2009, 115). Consequently, this these pathologies used to be grouped together as a single health indicator. However, researchers have discovered that while these pathologies can coexist in an individual -- PH can occur without CO, and CO can occur without PH -- meaning they could be responses to the same deficiencies, but they can also be responses to two different deficiencies as well (Brickley 2018, 897; Walker et al. 2009, 111). The porosities associated with both conditions are the result of diploic expansion as a result of marrow hyperplasia and the increased need for RBCs. CO may be more commonly found, however, because of the relatively thin bone in the orbits so porosity expression may happen more easily, or because it presents earlier on the skeleton than PH. While porosities on the parietals are associated with anemia, CO is more ambiguous. For example, scurvy and tumors can cause porosities of the orbits without porosities on the cranial vault bones (McFadden and Oxenham 2020, 207).

Porosities in the cranial bones are more common in children because yellow marrow begins to replace red marrow in the cranial bones at around age 15, porosities will no longer occur in the crania because these areas are no longer filled with red marrow, the production sites of RBCs (Brickley 2018, 900; Walker et al. 2009, 111). If an individual does have signs of PH and/or CO, the pathologies resulting from anemia occurred prior to age 15 and were likely the result of anemia during or throughout childhood.

3.3 Scoring of Lesions

The scoring of PH and CO has had its challenges since the original documentation of these porosities. Welcker was the first to describe and score porosities of the superior orbits and cranial vault using a scale of weak, strong, and strongest in order to note the size and severity of the pathologies (Jacobi and Danforth 2002, 249). However, most studies published prior to the 1980s did not evaluate the characteristics of the porosities but instead just recorded the presence or absence of porosities associated with PH and CO and whether or not the porosities have been remodeled (Lallo et al. 1977, Mensforth et al. 1978).

In 1985 Stuart-Macadam proposed a scoring system for scoring the severity and amount of these porosities on a scale of 1 to 3 (Stuart-Macadam 1985, 392). A score of 1 was defined by fine foramina, a score of 2 was defined as large and small foramina, and a score of 3 was defined by outward bone growth with foramina (Stuart-Macadam 1985, 392). While these comprised the first set of scoring standards to include a more rigorous scale, they were not accompanied by pictures demonstrating the differences among the scores; therefore, there was room for various interpretations among researchers that could cause a higher degree of interobserver variability and error.

Standards for Data Collection from Human Skeletal Remains by Buikstra and Ubelaker (1994) set forth new more rigorous and widely accepted standards with which to score PH and CO and were accompanied by several photos corresponding to the various levels of presentation. A score of 1 is given when the porosity is barely discernible but still present. A score of 2 is defined by more significant porosities in either the amount or severity of porosities present. A score of 3 is characterized by complete foramina in the bone, and a score of 4 is complete foramina accompanied by thickening of the bone. Photos of these various levels of severity can be found in the next chapter of this thesis that discusses Materials and Methods.

Jacobi and Danforth (2002) investigated interobserver error using the standards set forth by Buikstra and Ubelaker (1994), specifically looking at their efficacy and replicability. In this study, participants with various levels of experience in observing PH and CO were provided photos and definitions of the standards and then asked to evaluate a series of crania with different appearances of lesions. They found that the highest degree of agreeability occurred in crania that had either very severe or very mild lesions, but that most cases had 50 percent agreeability or less concerning the specific lesion score (Jacobi and Danforth 2002, 254). The researchers noted that the scoring standards were effective in establishing if a pathology is present or absent, but that scoring lesion severity was not as effective (Jacobi and Danforth 2002, 255). They propose this most likely could be due to those participating in the study anticipating the cases to have a high rate of porosities compared with the average amount of porosities for archaeological populations (around 25% have one or both pathologies present) (Jacobi and Danforth 2002, 255-256).

In order to reduce interobserver error, Jacobi and Danforth suggest that the standards have more rigorous definitions accompanied by more detailed visual examples including a range of porosity diameter and/or number of pores present for each score (Jacobi and Danforth 2002, 256). They also propose that the standards display photographs of the minimum and maximum of each score versus displaying photographs of a typical case for each degree score (Jacobi and Danforth 2002, 256). While Buikstra and Ubelaker's (1994) standards are widely accepted and used for comparison in various studies, there is room for improvement to eliminate as much subjectivity as possible in order for studies to be more accurate on their own, as well as more comparable to one another and between researchers.

3.4 Summary

Overall, while PH and CO have clear pathological symptoms such as porosities and possible bone thickening, the physiological cause of these pathologies is not as easily distinguished. While we know these pathologies are caused by some form or combination of anemia, research shows that iron deficiency anemia is not to blame as paleopathologists once thought since iron deficiency anemia does not cause the pathological symptoms seen with PH and CO. It is likely that the cause of these pathologies is more closely related to other forms of anemia, specifically megaloblastic anemia resulting in a vitamin B12 and/or folic acid deficiency; however, it is likely a combination of deficiencies that cause these lesions. Though the standards available could be improved some to help researchers achieve a higher rate of agreeability, using the newer, more widely accepted scoring standards for PH and CO (Buikstra and Ubelaker 1994) may allow paleopathologists to better understand how these pathologies compare across various populations and regions which can in turn lead to a better understanding of the anemia or deficiencies that cause these pathologies. Therefore, much could potentially be gained by re-evaluating CO and PH in the Tipu population to better understand their responses to Spanish contact.

CHAPTER IV - MATERIALS AND METHODS

In this chapter I discuss my sample and the criteria I used for this sample such as what bones were used for the sample and my criteria for adults. I also discuss the subgroups I explored and the criteria I used for each subgroup. Next, I discuss my methods and the scoring system used to analyze these samples including photos of what constitutes each score. I then explain what statistical analysis I will be using, and, finally, I give my hypotheses for this study and its results.

4.1 The Sample

The remains of the Maya population of Tipu are housed at the University of Southern Mississippi. Of the nearly 600 burials recovered, 588 burials represent the historic or contact period with the remainder dating to the Postclassic period (Cohen et al. 1994, 123). As the focus of this study was the adults of the population, all individuals aged 17 and under as well as those of an unknown age were excluded, providing a preliminary sample size of 281.

Next, I checked the inventories in the files of these 281 sets of remains as to whether they had crania or cranial fragments suitable for scoring. The focal bones were the parietal(s) and/or the frontal bone, specifically the frontal squama, superior orbits, parietal bosses, and the parietals along the midline/sagittal suture. Excluded were burials with crania that were too fragmentary, whether it be unidentifiable fragments or fragments smaller than 5cm by 5cm, or those burials that had been subjected to extensive taphonomic changes on the external surface of the bone where these pathologies would be visible. This narrowed the final sample size down to 81 burials for PH and 60 for CO.

For each burial, I recorded the age, sex, and social status. Age was broken into three groups: 18 to 25 years old, 25-35 years old, and 35+ years old; previous estimations made based on standard pelvic and cranial indicators, including pubic symphysis and auricular area morphology, suture closure, and dental wear (Buikstra and Ubelaker 1994) were used. Sex originally had been scored on a scale of 1 to 4 with 1 being male, 2 being female, 3 being probable male and 4 being probable female, again using standard skeletal indicators on the skull and pelvis, including pubic morphology, size of sciatic notch, brow ridge prominence, and size of mastoid processes (Buikstra and Ubelaker 1994). However, I condensed these into two categories of male/probable male and female/probable females. For this study, burial location was used as a proxy for social status, and information was determined based on where the individual was interred relative to the church. Those interred in the front half of the nave closest to the altar were given the value of 1; those buried in the back half of the nave were given the value of 2, and those recovered outside the church a value of 3. The final age/sex/burial location distributions for each condition are noted in Tables 4.1 and 4.2.

Table 4.1 *Sample Scored for PH by age, sex, and burial location.*

	Young Adults		Middle Ages Adults		Older Adults	
	M	F	M	F	M	F
Inside Church Front	2	1	7	4	1	0
Inside Church Back	6	1	3	1	0	0
Outside Church	17	2	16	12	2	4
Total	25	4	26	17	3	4

Table 4.2 *Sample Scored for CO by age, sex, and burial location.*

	Young Adults		Middle Adults		Older Adults	
	M	F	M	F	M	F
Inside Church Front	2	1	6	3	0	0
Inside Church Back	2	1	3	1	0	0
Outside Church	15	2	13	8	2	0
Total	19	4	22	12	2	0

4.2 Methods

In order to assess the PH and CO on the crania, I used the scoring procedure set forth in Buikstra and Ubelaker (1994, 151-153), observing the frontal squama and entirety of both parietals. While porosities can co-occur in all these areas, they can also occur independently of one another by region, so the bones were scored separately to get a more accurate reflection of the presence of lesions. I noted as well the severity degree of the porosities and whether there was remodeling present.

For both conditions, if no porosity was discernible on the bone surface, a score of 0 was recorded. If porosity was barely discernible on the cranium or orbits (Figure 6), a score of 1 was given. A score of 2 indicates that there is a more significant amount or severity of porosity, as seen in Figure 6. A score of 3 is defined as porosity that is severe enough to form complete foramina in the bone and can be seen in Figure 7. Lastly, a score of 4 would look the same as a score of 3, but with the addition of bone thickening which is cause by the expansion of the marrow, also known as diploic expansion, which is indicative of the most severe cases of PH and/or CO (Buikstra and Ubelaker 1994, 151-153; McFadden and Oxenham 2020, 210). Presentation of porosities associated with PH and CO are seen in Figures 4.1-4.4.

Figure 4.1 *PH porosities (seen in on right side consistent with a score of 1. (Buikstra and Ubelaker1994, 153).*

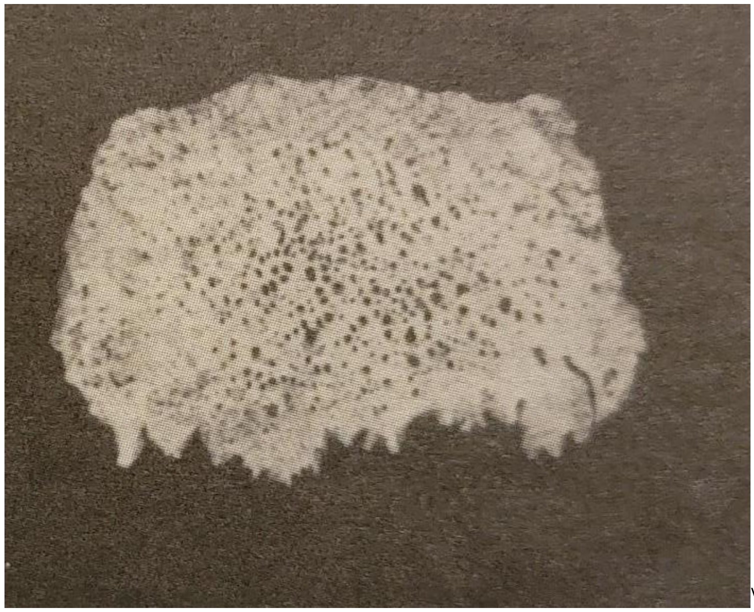

Figure 4.2 *PH porosities consistent with a score of 2. (Buikstra and Ubelaker 1994, 153)*

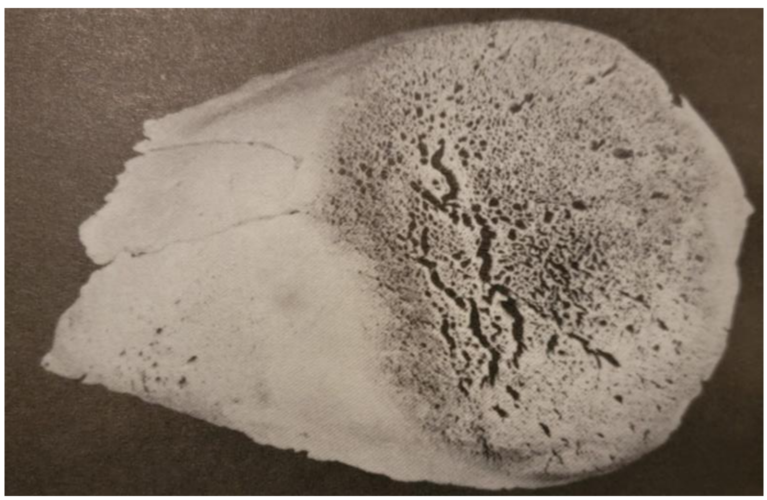

Figure 4.3 *PH porosities consistent with a score of 3 (Buikstra and Ubelaker 1994, 153)*

Figure 4.4 *CO porosities representing a score of 2 on the left side of the photo (right orbit) and a score of 3 on the right side of the photo (left orbit) (Buikstra and Ubelaker 1994, 151)*

Scoring remodeled porosities uses a similar scale with a score of 1 being active porosities and a score of two constituting any healing at the time of death up to complete remodeling (Buikstra and Ubelaker 1994, 151). Newer porosities give the bone a hair-on-end appearance whereas remodeling porosities are smoother and more rounded as the pores begin filling with new cortical bone.

4.3 Statistical Analysis

After scoring all adults in the sample for these pathologies, data were entered into an Excel spreadsheet. Using SPSS-Version 28 (IBM Corp. 2021), lesion frequency and expression were compared by sex, age, and burial location and then were tested for statistical significance using Chi-squared analysis.

4.4 Hypotheses Tested

The following hypotheses are considered in the analysis of the data collected:

1) The Tipu population will have moderate rates of PH and CO compared to other Maya sites; additionally, most lesions present will be of mild to moderate severity and will be remodeled.

2) Younger adults will have higher rates of PH and CO that older adults;

3) Males will have greater rates of PH and CO than do females, both in general and by age; and

4) Those of higher status, as indicated by burial location within the church nave, particularly those closer to the altar, will have lower rates of PH and CO than those buried towards the back of the nave and outside the church altogether.

The rationale for these hypotheses was discussed in the introduction of this thesis and was further established in the literature review. The results of this analysis of PH and CO in the Tipu population are presented in the next chapter.

CHAPTER V - RESULTS

This chapter discusses the results of scoring PH and CO in adults over the age of 18 at Tipu. In order to analyze the population, I explored the differences in the presence of PH and CO using a score of 1 or higher as present and a score of 0 as not present; I also noted the degree of severity and whether the lesions were remodeled. Using these parameters, I address the differences between various age groups (18-25, 25-35, and 35 and older), as well as differences between the sexes (male and females), differences between the sexes among the three age groups, and differences in burial location (inside the front of the church towards the altar, inside the back of the church farthest away from the altar, and outside the church). I investigate the difference in frequencies of the presences of these pathologies between these groups as well as the overall presence of PH and CO among the entire population.

5.1 Porotic Hyperostosis

Of those 81 individuals in the sample, 38 individuals (46.91%) were found to have PH while 43 (53.09%) showed no signs of PH. Of the 38 individuals with lesions, 35 individuals had a score of 1 and three individuals had a score of 2; thus, the great majority of those with porosities appear to have had mild cases of the condition. No pathologies were observed were considered severe enough to warrant a score of 3 or 4, and none of the individuals at Tipu had active PH and CO. All individuals scored in this study were in various stages of remodeling. Figure 5.1 shows percentages of the various levels of PH in the population of Tipu.

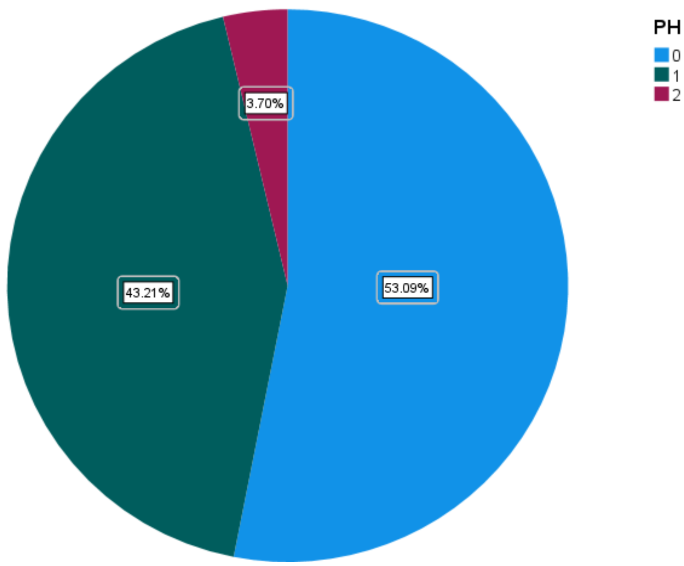

Figure 5.1 *Frequency of severity of PH in adult individuals at Tipu (N=81).*

Next, I explored the differences in the presence of PH based on age. I separated the sample into the age groups: individuals aged between 18 to 25, aged 25 to 35, and aged 35 or older. The group with the highest number of individuals with PH was the youngest group with 65.52% (19/29) having lesions. The other two groups had similar frequencies with 36.36% (16/44) of individuals aged 25 to 35 and 37.5% (3/8) of individuals aged over 35 showing signs of PH. The results of these differences were found to be statistically significant with the youngest group having the highest rates of PH (X^2= 6.281, P= 0.043, df= 2). The data for the individuals in this group can be seen in Figure 5.2.

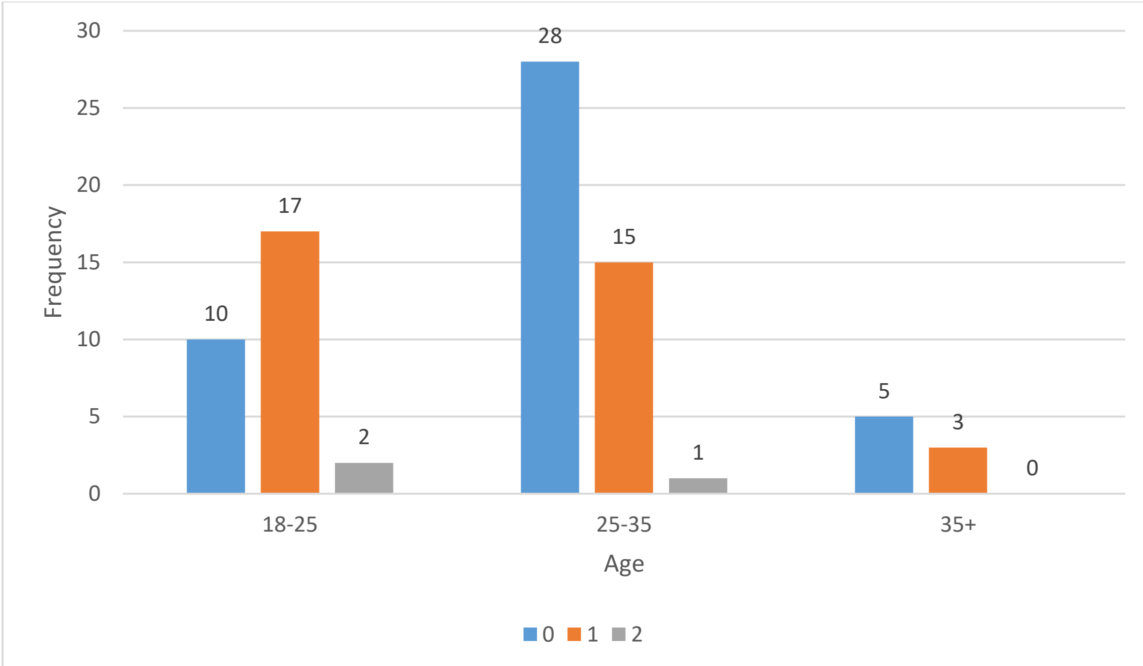

Figure 5.2 *Frequency and severity of PH in adult individuals at Tipu by age (N=81).*

I then examined the differences in the rates of PH by sex. Among males, 62.5% (35/56) had PH as opposed to just 12% (3/25) of females presenting with PH. This difference was highly significant (X^2=17.699, P= <0.001, df=1). All cases of moderate or greater severity of lesions were seen among males (Figure 5.3).

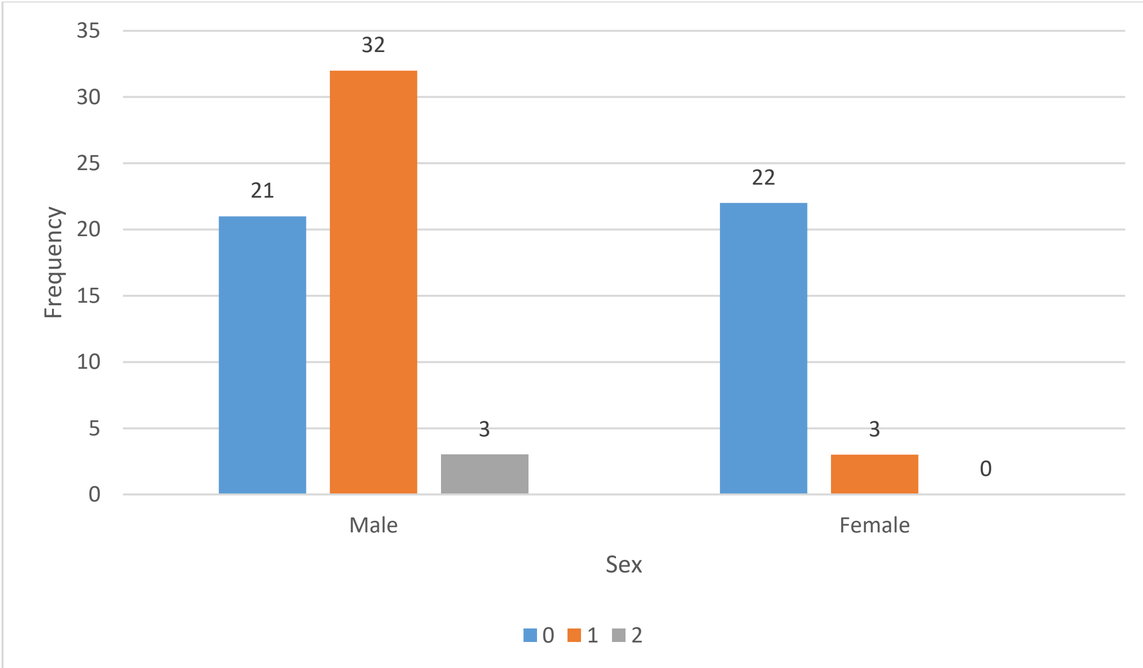

Figure 5.3 *Frequency and severity of PH in adult individuals at Tipu by sex (N=81).*

Next, I analyzed PH by age and sex to see if any patterns emerged. For each sex, I found that older males had the highest rates of PH (75%) whereas the youngest group of females had the highest rates of PH (50%). Older females had the lowest rate of PH as everyone in that group had a score of level 0. Male and female charts by age are featured in figures 5.4 and 5.5, respectively.

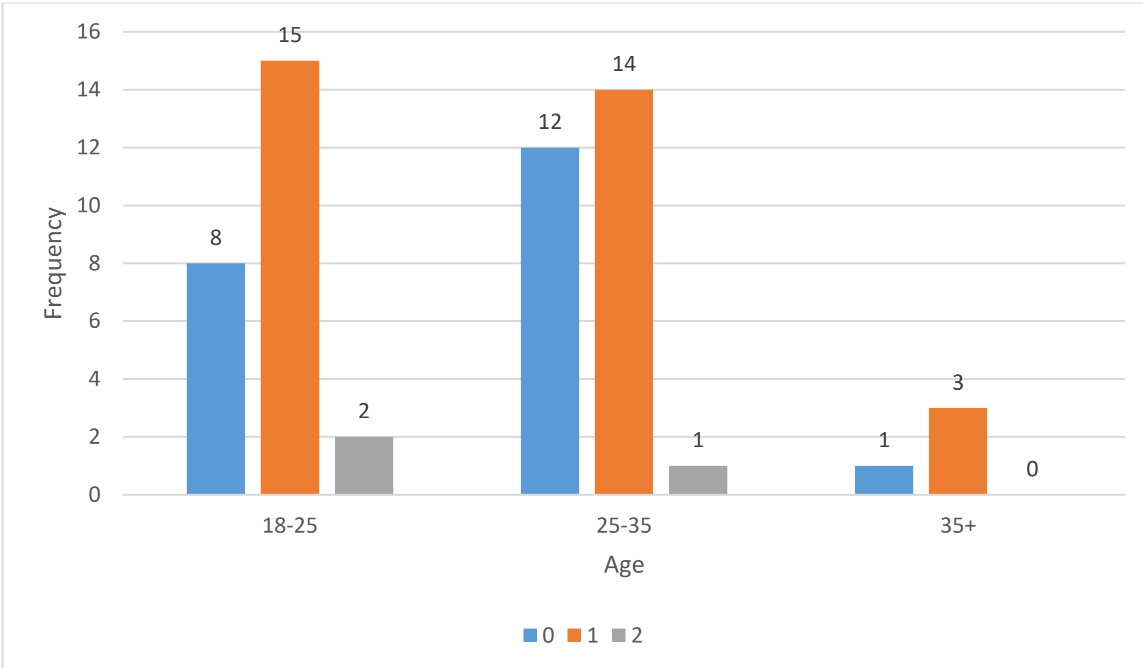

Figure 5.4 *Frequency and severity of PH in adult male individuals at Tipu by age (N=55).*

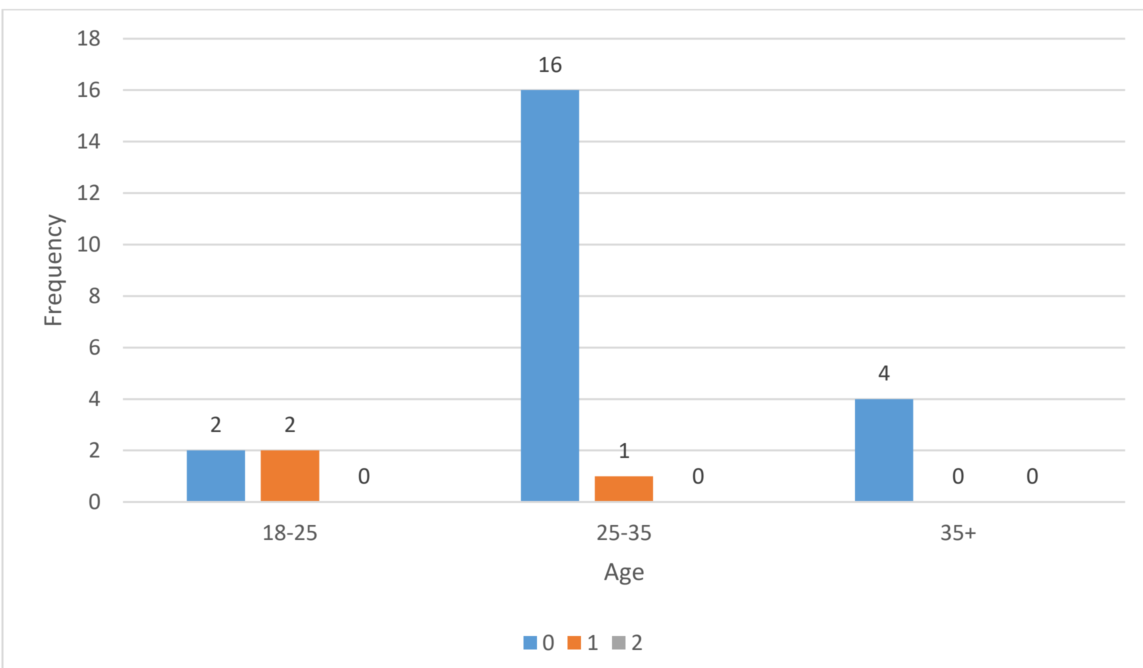

Figure 5.5 *Frequency and severity of PH in adult female individuals at Tipu by age (N=25).*

Finally, I explored the differences in PH based on burial location, which was used as a proxy for social status. The highest rates of PH were found inside the church towards the back with 81.82% (9/11) of individuals affected. Individuals buried inside the church near the altar had nearly half the rate of PH than those buried towards the back of the church with lesions being present in 46.67% (7/15) of individuals. However, individuals buried outside the church had the lowest rate of PH with 37.74% (20/53) of all, showing signs of PH. The results of this analysis can be seen in figure 5.6. These findings were found to be statistically significant (X^2= 9.437, p= 0.024, df=3).

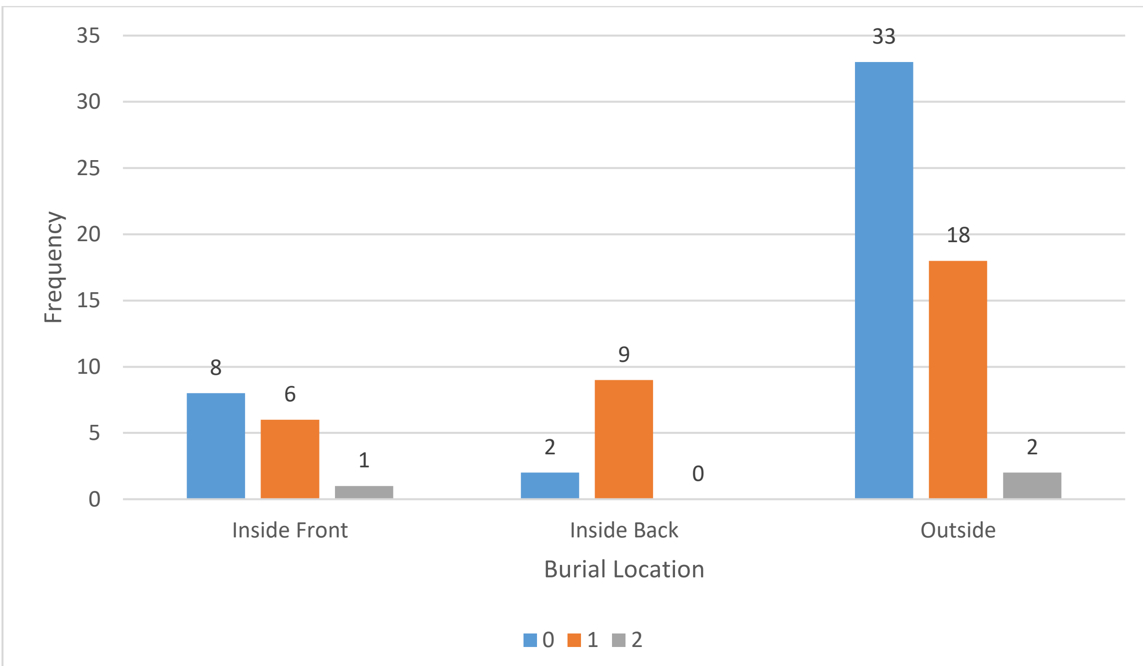

Figure 5.6 *Frequency and severity of PH in adult individuals at Tipu by burial location (N=79).*

5.2 Cribra Orbitalia

The sample size of adult individuals with bony elements associated with CO, the superior orbits, was 60. Of those 60, 13.34% (8 individuals) had CO lesions while 86.67% (52 individuals) showed no signs of this pathology. Of the eight with CO, four had a score of 1 and four a score of 2. No scores above 2 were observed in this sample. The percentages of individuals for each score of CO can be seen in figure 5.7.

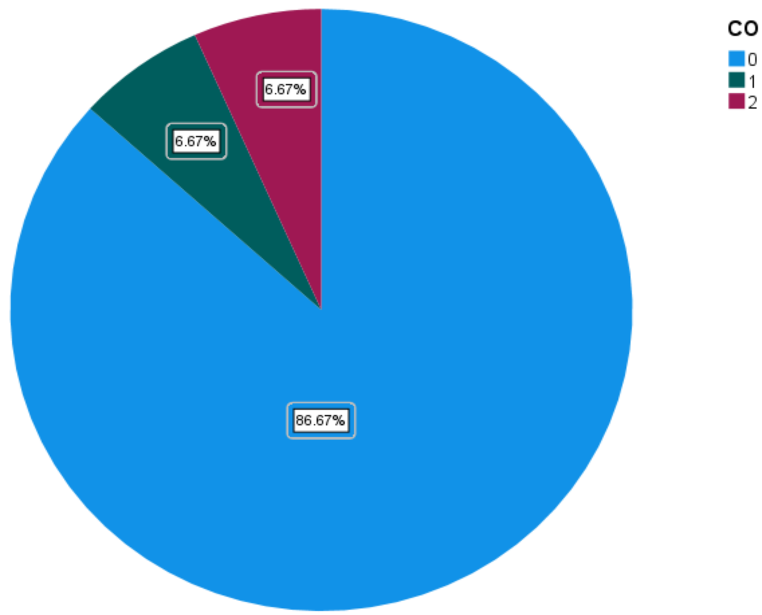

Figure 5.7 *Frequency of severity of CO in adult individuals at Tipu (N=60).*

I then analyzed the data for the presence of CO by age. Lesions were present in 17.39% (4/23) of individuals aged 18-25, as compared to 8.57% (3/35) of individuals aged 25 to 35; the group aged 35 and up had the highest rates of CO at 50% (1/2). I edited the age ranges of infection due to CO to 25+ to increase my older adult sample size for comparison. While these frequencies appear to show differences among these three groups, they were not found to be statistically significant (X^2= 3.341, P= 0.188, df=2). Results can be seen in figure 5.8. It was also found that younger individuals (18-25) had more moderate porosities than their older counterparts with 14% of the group scored as a level 2 (figure 5.8).

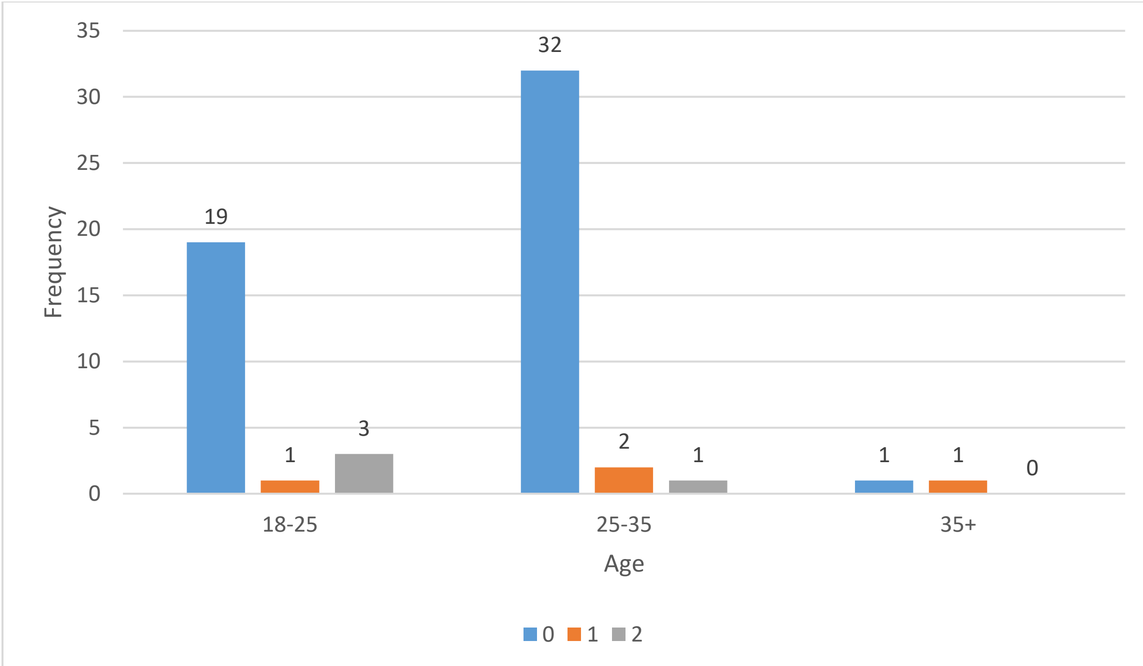

Figure 5.8 *Frequency and severity of CO in adult individuals at Tipu by age (N=60).*

Next, I compared the rates of CO by sex. Rates were very similar with 13.64% (6/44) of males affected and 12.5% (2/16) of females affected; not unsurprisingly these results were not found to be statistically significant (X^2= 0.013, p= 0.909, df=1). A comparison of males and females scored for CO can be seen in figure 18. I also found that males had slightly more moderate lesions with 7% of the male population scored as a level 2, whereas females with a score of 2 made up 6% of the sample as can be seen below in figure 5.9.

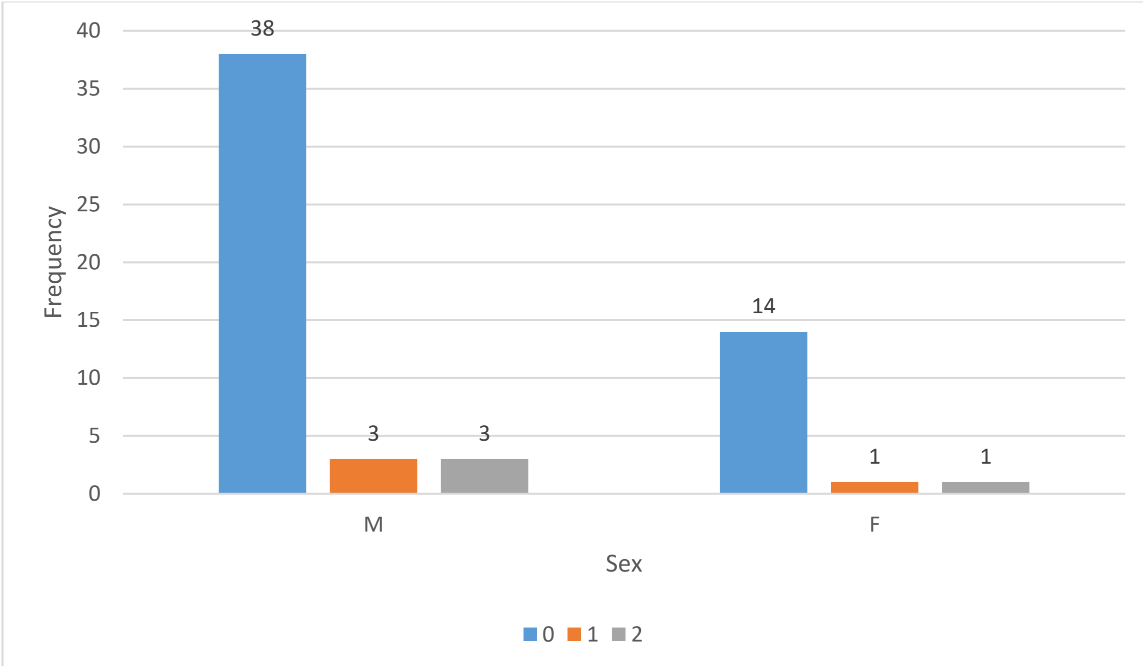

Figure 5.9 *Frequency and severity of CO in adult individuals at Tipu by sex (N=60).*

Next, I analyzed patterns of lesions in males and females based on the age groups. I found that, like PH, older males (35+) had the highest rate of CO (50%), however the sample size was extremely small for this group (2 individuals). In comparison younger females had the highest rate of CO among females, and again older females had the lowest rate between the sexes with 0 percent of that group having CO. Young males (18-25) were also found to have more moderate legions attributed to CO (nearly 11%) than males 25-35 and 35+. As with males, young females have a greater severity of lesions (25%) than their older counterparts of which none had a score above a level 1. Additionally young females have a greater level of severity than their male counterparts, but this may be due to a small sample size for females aged 18-25 (n=4). Results of the analysis based on males and females can be seen in Figures 5.10 and 5.11 below.

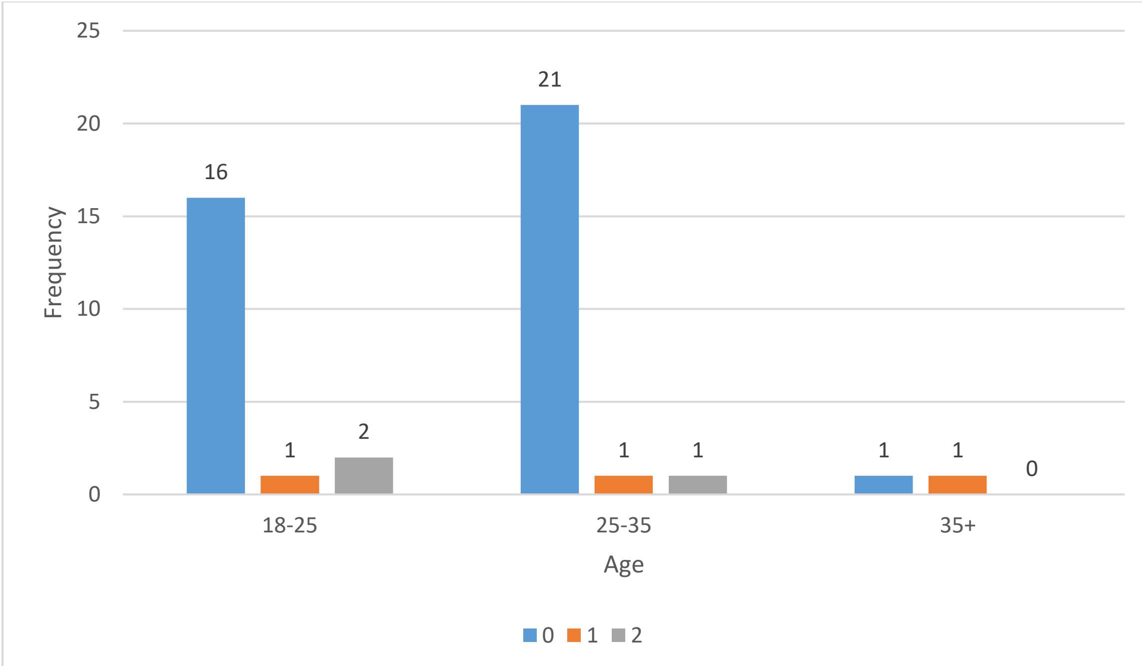

Figure 5.10 *Frequency and severity of CO in adult male individuals at Tipu by age (N=44).*

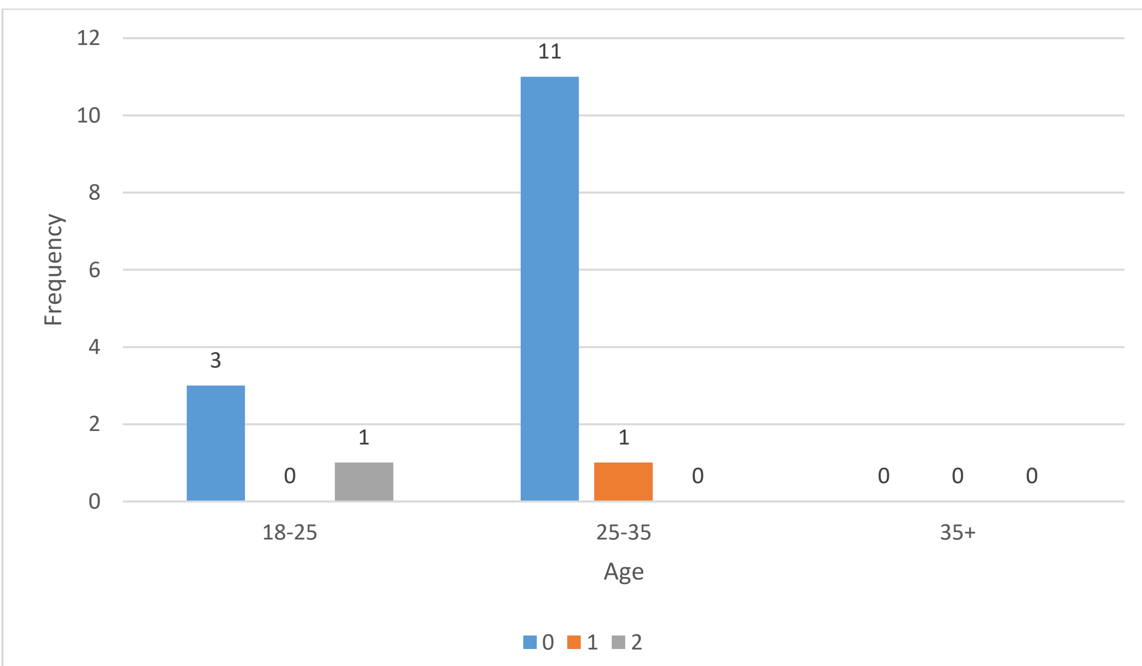

Figure 5.11 *Frequency and severity of CO in adult female individuals at Tipu by age (N=16).*

Finally, I explored the patterns of CO based on social status using burial location. Inside the back of the church, I observed the highest rate of lesions at 20% (1/5) of individuals while only 12.53% (1/8) of individuals buried inside the church towards the altar were found to have CO. Outside the church, rates were intermediate with 13% (4/30) of individuals having CO. These differences were not found to be statistically significant (X^2=1.844, p 0.605, df=3). When considering lesion severity, 20% of those buried inside the church towards the back were scored as a level 2 which can be seen in figure 5.12 below.

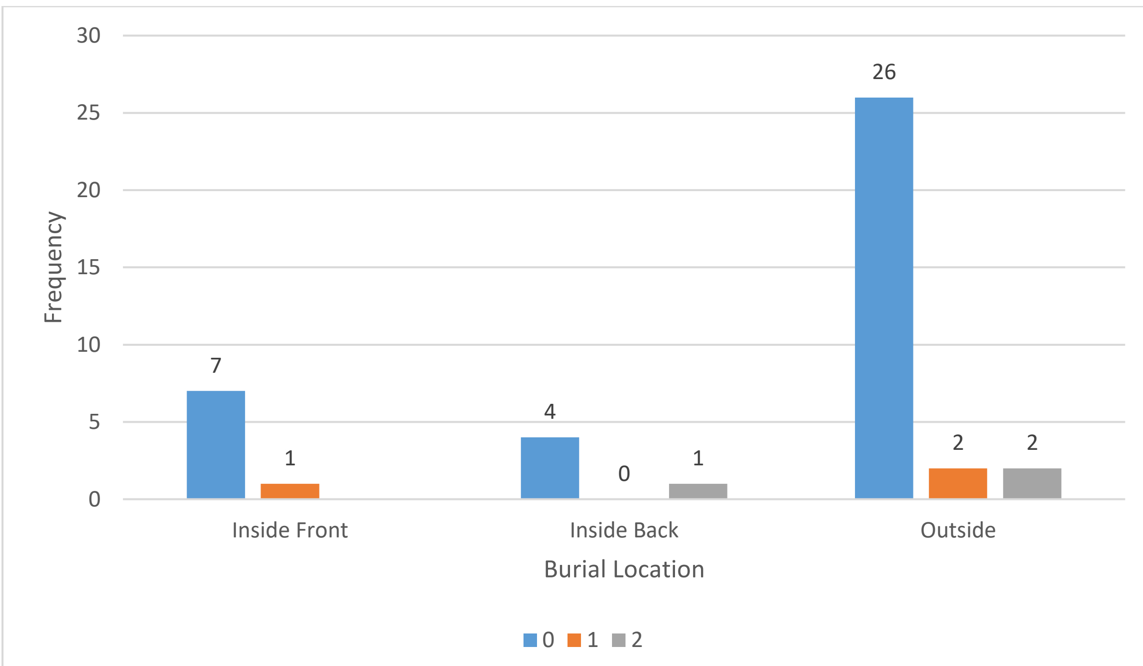

Figure 5.12 *Frequency and severity of CO in adult individuals at Tipu by burial location (N=43).*

In summary, PH is more prevalent than CO in the adult population at Tipu; perhaps even more notable is that in those individuals presenting with lesions, the porosities are all mild in most cases. PH is more likely to be found in younger adults whereas CO is more frequent in individuals older than 35, with the differences being statistically significant. When looking at PH and CO by sex, males were much more likely to suffer from PH than were females, again a distribution difference that was significant. However, males and females have similar rates of CO, although rates are below 15% for both groups. Findings based on status using burial location found that individuals buried in the back of the church furthest from the altar were more likely to suffer from both PH and CO. The lowest rates of CO occur in the front of the church towards the altar, which was expected, but unexpected was that the lowest rates of PH were found in those buried outside of the church; none of the differences were statistically significant, however. Given the very few individuals with moderate lesions, and nobody with severe lesions, no meaningful patterns could be identified concerning severity. Possible explanations for the patterns discovered during analysis will be further explored in the following chapter.

CHAPTER VI - DISCUSSION

In this chapter, I first discuss the overall rates of PH and CO at Tipu and how they compare to a previous study of these porosities in the population completed before the most widely used current standards were in place (Buikstra and Ubelaker 1994). Then I consider various contexts that might result in the rates of PH and CO by age, sex, and burial location. Using these findings, I compare the site of Tipu in relation to other Maya populations throughout time and space, and possible reasons for the patterns are explored.

6.1 Comparison with Previous PH and CO Patterns Recorded at Tipu

The earlier evaluation of PH and CO at Tipu was conducted in the 1980s with data contributed by several laboratory workers, graduate students, and undergraduate students at SUNY-Plattsburgh at different times. When their data were compiled, it was seen that 24 percent of males and 12 percent of females had PH, and CO occurred in 9 percent of males and 5 percent of females (Danforth et al, 1997, 117). While those general trends are like those I found at Tipu, such as males having higher rates of PH and CO, the frequencies seen in the present study are dramatically larger.

This reflects the effects of the new scoring standard used in this study, especially in terms of noting the specific severity of lesions present. I found that nearly half (35/82) of PH scores were recorded as a level 1 expression whereas only about 4% (3/82) of PH are scored as a level 2. CO scores are like each other in that both scores 1 and 2 have equal rates at 6.5% each (4/61). The earlier evaluation of Tipu also may not have included individuals who had almost healed porosities. However, the results gained using the more well-established standards of Buikstra and Ubelaker (1994) do potentially put into new perspective the inhabitants of Tipu might not have been as insulated from nutritional stress as earlier concluded, although other indicators, such as their relatively tall stature, might suggest otherwise (Cohen et al. 1994).

6.2 General Patterns in the Tipu Population

Only considering data from the more recent standards (Buikstra and Ubelaker 1994), PH was much more common than CO at Tipu by a ratio of nearly 4:1. However, other research has shown that CO tends to be more commonly found than PH. Walker et al. (2009, 115) analyzed 217 skeletal collections from North and South America from 4,000 B.C. to the present, scoring 4419 individuals for PH and/or CO (Walker et al. 2009, 115; Steckel et al. 2002, 142). The researchers observed that 14.6% of the total sample presented with PH whereas CO was seen in 19.4% of the population (Walker et al. 2009, 115). In comparison, PH at Tipu occurred at a rate of nearly 47% whereas CO occurred in just over 13% of individuals; so, the CO rates are generally comparable between the two studies, but the PH rates differ greatly. In Walker et al.'s sample, 26.9% had both CO and PH, whereas only 8.64% of individuals at Tipu have both PH and CO (Walker et al. 2009, 115). Thus, the patterns seen at Tipu do not appear to be typical of many populations.

There are many possible reasons why PH is more prevalent than CO at Tipu. It was once thought that CO was a precursor to PH which could theoretically result in higher rates of CO than PH (Walker 2009, 109). However, Walker et al. (2009) and Rothschild (2000, 86) found that PH and CO co-occurred in only a portion of cases, thereby suggesting CO is not always a precursor to PH. One primary explanation could be reflective of the age at which these pathologies present based on red marrow production in the cranial vault versus the orbits (Brickley 2018, 900). Red marrow production centers in the orbits stop producing red marrow and turn to yellow marrow by 11 years old (Brickley 2018, 898). However, red marrow production converts to yellow marrow production in the cranial vault bones by age 16 (Brickley 2018, 900), thereby allowing PH lesions to persist longer.

Another explanation could involve age distribution differences among the samples discussed. Wright and Chew (1998) found that older individuals may have lower rates of PH and CO due to remodeling that occurs throughout life. My study was based on only on adults aged 18+ whereas Walker et al. (2009) included individuals from newborns to the elderly. Therefore, it is possible that CO had more time to heal in a larger part of the Tipu sample, and perhaps become more imperceptible than PH. I noted that PH and CO are found more commonly in the youngest age group of this study (18-25 years old) which could reflect less time for remodeling to occur (Brickley 2018, 898).

There is also evidence that PH and CO may have causes other than just various forms of iron-deficiency, such as CO being more reflective of scurvy (Ortner and Ericksen 1997; Zuckerman et al. 2014, 27). Gomberg (2018) found that 27% of the population at Tipu presented with mild scurvy. Children aged 6-15 had the highest rates and those older than age 30 had the lowest; adult males also had higher rates of scurvy. These match the patterns of CO at Tipu, so it is possible that some of the lesions may be attributable to scurvy as well as megaloblastic anemia.

Although the rates of PH and CO at Tipu were lower than those in Walker et al.'s (2009) large study, they vary in comparison with those seen at other premodern Maya sites. Classic period Copan in Honduras had an average of 60% of adults presenting with PH (Whittington 1989), and Altar de Sacrificios from the same era in Guatemala exhibited an even higher rate with 89.3% of adults presenting (Saul 1972, 1973). In comparison, the mission site of Lamanai in central Belize, which was analogous to Tipu in date and function, had just 17% of the historic population exhibiting PH (White 1988). Another Postclassic/Historic site located in the highlands of Guatemala, Iximche, was found to have a combined rate of 16.1% of adult and subadult individuals with PH (Whittington 1998).

Thus, Tipu has lower rates of PH than the Classic Maya centers but markedly higher rates than the more contemporaneous sites. It is documented that there was an influx in the population at the site in the mid-1600s (Graham 2011), and populations conquered by the Spanish were under tremendous stress as they experienced reorganization of social structures, were used as forced labor, and endured both religious and dietary shifts (Oland and Palka 2016, 474). All this in combination could lead to changes in diet associated with nutritional stress (Oland and Palka 2016, 476). However, given the PH/CO frequencies at Tipu, the resulting strains may not have been as intense as placed on the populations at the larger Late Classic sites – for example, there may have been up to 100,000 inhabitants at Tikal (Coe 1999) – exceeded limits of food supply, adequate sanitation, housing conditions, and other such factors that would cause higher rates of PH.

Various explanations for the frequencies at Tipu relative to those seen at other sites are possible. Ethnohistorical records note that refugees fled areas under more direct Spanish control to unconquered zones like Tipu (Oland and Palka 2016, 474). These immigrants may have grown up under much more stressed conditions, and their presence at Tipu may be responsible for the higher rates of PH and CO than at other historic sites considered, including Lamanai which was also inland but did not serve as a refugee center. Using isotope analysis, Trask (2018) identified that about two-thirds of Tipu's population is comprised of nonlocal individuals, and it is possible that they encountered greater nutritional stress during childhood (Graham et al. 1989, 1255, 1258). It is also possible that the local children at Tipu were not insulated from nutritional stress. However, the potential role of differing scoring standards must still be kept in mind in that both Copan and Altar de Sacrificios had notably higher frequencies of other health markers, such as infection and LEH, than did Tipu (Saul 1973; Storey et al. 2002). Furthermore, most of the cases of PH and CO at the site are marked by slight lesions.

Frequencies of CO are reported much less often than those for other Maya populations. It is possible earlier studies of PH include CO since these were once seen as the same affliction, because of this, it is unclear if previous studies of PH include CO in their analysis, and if they do, it could bolster the rates of PH at comparable sites. I was able to find data for prevalence of CO separate from PH for only four Maya sites: Copan, Jaina, Palenque, and Xcaret. At Copan in Honduras, 40% of the population was found to have CO, and similar rates of CO were found at the site of Jaina, a Classic Maya site located in modern Campeche, with 37.5% of the population having porosities consistent with CO (Marquez Morfin and Hernandez Espinosa 1982, 230). Palenque, a Classic site in Chiapas, had the highest rates of CO with 80.8% of the population affected, and Xcaret, a Postclassic site in Yucatan, had the lowest rate at 25% (Marquez Morfin and Hernandez Espinosa 1982, 230).

While these rates are much higher in comparison to the CO rate of 13.34% of adults at Tipu, they do include subadults; unfortunately rates for adults only were not reported. Thus, these results are inconclusive since the generally higher prevalence of CO in juveniles is a result of nutritional stress during childhood (Brickley 2018, 898; Walker et al. 2009, 111).

6.3 Age Differences in Frequencies

I hypothesized that younger adults at Tipu would have higher rates of PH and CO than their older counterparts, and, as expected, PH was more prevalent in those aged 18-25 than in those over age 25; in fact, the younger group had nearly double the rate which was found to be statistically significant (X^2= 6.281, P= 0.043, df=2). The younger group was also found to have porosities of greater severity than older individuals. Lower rates among older individuals were expected due in part to the fact that older individuals had a longer duration for remodeling of porosities associated with PH (Wright and Chew 1998). However, another explanation as to why PH rates may be higher in younger adults is the Fetal Origins of Adult Disease hypothesis, previously known as the Barker Hypothesis. The original hypothesis argues that individuals who experienced higher rates of illness in childhood, especially as fetuses and infants, are more likely to have shorter life expectancies as adults due to increased likelihood of incurring conditions such as cardiovascular disease, chronic bronchitis, and diabetes, among others, later in life (Armelagos et al. 2009, 263, Barker 2002; Barker et al. 1989). The potential effects of the Barker Hypothesis could also be an explanation for the findings seen in Gomberg's 2018 analysis of scurvy at Tipu. She noted that younger adults had higher rates of the condition and also of infection/periosteal conditions (Gomberg 2018, 58).

The Barker hypothesis was later modified and became the Developmental Origins of Health and Disease hypothesis (DOHaD). While the Barker hypothesis argues that periods of stress in utero and in relation to maternal health led to adverse outcomes for health in adults, the DOHaD hypothesis argues that things such as health, diet, environment, and disease in early life lead to adverse outcomes later in life (McFadden and Oxenham 2020, 210). It has been found that childhood malnutrition can lead to a higher susceptibility to respiratory, gastrointestinal, and systemic bacterial infections due to immune function being compromised (McFadden and Oxenham 2020, 211). This susceptibility to disease would cause a higher mortality rate because innate and acquired immune responses may not be effective against nutritional deficiency (McFadden and Oxenham 2020, 211). Therefore, those with robust immunity during exposure to nutritional deficiency, such as anemia, may have a better outcome than those with a frail immune system, frailty being a higher susceptibility to disease and mortality due to pre-existing condition, prior health insults, and/or genetic factors (McFadden and Oxenham 2020, 211). It has also been found that periods of illness early in life can reduce the effectiveness of immune responses later in life which could then cause a higher mortality rate as adults (Watts 2013, 95). Essentially, a trade off happens where individuals survive disease in early childhood, but then are more susceptible to disease as adults (Klaus 2014, 295; Watts 2013, 95). Because of this trade off, it is possible that younger individuals have higher rates of PH and CO because they are more susceptible to illness, specifically anemia, and have a higher frailty than those that survived in the older group. It is also possible that those who were sicker as children are more susceptible to anemia and have a higher mortality rate as adults as well.

I also expected that younger individuals will have a higher prevalence of CO, again due to older individuals having a longer duration for the porosities to heal. Initially

I found that the highest rates of infection were technically in the 35+ group, but this number likely was not representative since there was only one individual in the age group who was affected. Because of the small sample size I readjusted the age ranges of infection due to CO to 25+ to increase my older adult sample size for comparison. When making these changes to the age ranges, individuals 18-25 years old had the highest rates of CO which again may be due to the healing of porosities reducing the ability to recognize lesions as well as the effects of the DOHaD.

6.4 Sex Differences in Frequencies

I anticipated that males had a higher prevalence of PH, and this was strongly confirmed as lesions among males were nearly four times higher than in their female counterparts. Males also had more moderate lesions than their female counterparts who had mild lesions. As with the age patterns seen, this difference by sex can be attributed to various physiological factors. Stini (1969) found that when a female's growth was stunted, their bodies returned to normal rates when more advantageous conditions returned whereas their male counterparts did not (Stini 1969, Stinson 1985). Stinson (1985) reported that while males have higher rates of late fetal mortality, the results of investigations of responses to postnatal environmental stress by sex are inconsistent, likely due in part to the fact that the Maya, like most societies, gave males preferential treatment, even as children (Storey 1992). Therefore, it is possible that the high rates of PH and CO among males at Tipu can be attributed to innate buffering for females as females at Tipu had lower rates of other childhood health disruption, such as linear enamel hypoplasias and Wilson Bands (Danforth et al. 1997, McFadden and Oxenham

2020, 212). It has also been found that males are 1.6 times more likely to suffer from anemia than their female counterparts (McFadden and Oxenham 2020, 212).

However, it is also likely that cultural factors were also affecting patterns of PH and CO at Tipu. Maya children were put to work based on gender roles from a very early age and differentiation based on sex occurred around ages 4 to 8 (Arden and Hudson 2006; Storey and McAnany 2006, 54). By the age of 6 or 7, females were already completing tasks, such as weaving, and males started adult activities, especially ones associated with subsistence, between 10 and 13 years old (Storey and McAnany 2006, 54). Adult males in particular would have consumed more maize as a result of "eating out" while farming as compared to their female counterparts (Arden and Hudson 2006; Storey and McAnany 2006, 54), a finding supported by isotopic analysis (White et al. 1993). It is possible that young boys working alongside them in the fields followed suit. Females would have been better insulated against nutritional stress consuming more nutrient rich foods, such as leafy greens, fruit, and peppers (Arden and Miller 2020, 5) in the kitchen gardens they tended in addition to benefiting from the protections offered by the insulation against nutritional stress that females are afforded (White et al. 1993, 348). Because of these trends, factors affecting rates of PH and CO would present at the same time the conditions would be afflicting children, although again most cases were relatively minor. In turn, this would account for the differences among the rates of PH and CO between males and females at Tipu.

When analyzing CO by sex, only a marginal difference in the rate of CO in males and females was found, with females having slightly lower rates than males. This could be attributed to the small sample size of those with CO. However, since CO occurs in early life, usually before age 8, it may have presented before differentiation between the sex's cultural roles occurred. Both PH and CO are more common in males, agreeing with Gomberg's analysis of scurvy at Tipu (2018), although, her CO differences were not found to be statistically significant.

6.5 Age and Sex Interaction

PH and CO were next considered to see if there were any significant differences among age groups by sex. While females did follow the expectation of the younger individuals (18-25) having higher rates and older individuals (35+) having lower rates of PH, males did not initially appear to follow this trend. However, one group (older males) only had a sample size of three, so I consolidated the age groups for males into 18-25 and 25+ years old. The younger male group subsequently did have higher rates of PH than the older group; however, these findings were not statistically significant. Young males and young females also had a greater severity of porosities being scored as a level 2 than their older counterparts. Thus, all expected patterns by age and sex for the condition were seen at Tipu. When the PH results by age and sex at Tipu were compared with those at Xcaret, the same trends with young males having higher rates of PH than young females were seen (Storey, Marquez Morfin, and Smith 2002, 292).

Patterns of CO by age and sex at the site showed males having lower rates of CO at nearly each age interval. Males had lower rates of CO than females in the 18-25 and 25-35 age group. This was not expected as I expected males to have higher rates of CO at each age interval than their female counterparts due to females being better insulated against nutritional stress (McFadden and Oxenham 2020, 212). Again, this possibly reflects the more varied causes suggested for CO being in operation. No comparative studies for CO at other Maya sites could be identified.

6.6 Status Differences in Frequencies

Lastly, I analyzed the rates of PH and CO by burial location at Tipu, hypothesizing that individuals in the nave of the church would have lower rates of PH and CO than those buried outside the church as a result of their higher status (Cohen et al. 1994); furthermore, those closer to the nave would have had even more privilege than those buried at the back (Jacobi 2000). This higher status would have theoretically caused them to have been better insulated from nutritional deficiencies from greater access to nutrient rich foods, especially meat resources.

I found the group with the highest rates of PH and greatest severity were found toward the back of the church, which was expected. However, those with the lowest rates of PH were found outside the church, which was unexpected. This frequency was closely followed by those of individuals buried inside the front of the church. One possibility is that those buried inside the church were more likely to be among the immigrants who may have grown up under more direct Spanish control and thus had more adherence to Christianity than Tipu locals and were more desirous to be buried in the church. Given that many of these immigrants also may have spent their childhoods in areas with greater disruption, including economic practices, due to Spanish contact, their nutritional statuses could have been adversely affected (Graham 2011, 197; Graham et al. 1989). Unfortunately, this hypothesis cannot be currently tested.

In analyzing CO, I found that those at the back of the church had the highest rates of CO, and the lowest rates of CO were found at the front of the church near the altar, both of which were expected. However, these results were not found to be statistically significant likely due to the sample size being relatively small for each group. Given the sample sizes of those affected with CO in the various burial locations were very small due to relatively low rates of the condition at Tipu, findings must be taken with caution.

6.7 Summary

The levels of PH and CO at Tipu are situated in the middle of Classic and Historic era sites. However, it must be remembered that most lesions seen at Tipu were slight in their presentation, and also it is unclear what scoring systems were used for previous studies at other sites. Patterns of other childhood health markers and infection such as LEH, Wilson bands, and scurvy (Cohen et al. 1994, 1997; Danforth et al. 1997; Gomberg 2018) suggest that Tipu is a relatively healthy population. Thus, the severity although perhaps not frequency of PH and CO are in general agreement with these findings.

PH at Tipu does have higher rates than those seen at other contemporaneous sites in the region. It is possible that the influx of refugees put a strain on local resources which could account for the higher levels of PH in all categories studied (age, sex, age and sex, and burial location) at Tipu. When prevalence of the two conditions is considered by sex, females being better insulated against nutritional stress played a role in keeping females' levels of PH and CO lower than their male counterparts such as the differentiation of the sexes and the introduction of refugees fleeing more direct Spanish control, as well as physiological reasons (Arden and Hudson 2006; Storey and McAnany 2006, 54; Trask 2018).

When patterns within the sample were considered, older individuals were found to have lower rates of PH than younger individuals. In addition to the opportunity for greater remodeling of lesions with a longer life, there is also the possibility that those with severe infection succumbed to illness earlier in life, which would cause lower rates of PH among older adults. Finally, individuals buried at the back of the church at Tipu had the highest rates of porosities associated with PH, but those buried outside the church had the lowest rates of PH. Thus the role of status on PH frequencies is not clear. However, it is evident that the PH and CO levels at Tipu can be attributed to interaction of a variety of factors as the individuals adapted with both accommodation and rebellion to life on the Spanish frontier.

CHAPTER VII - CONCLUSION

Tipu was an early colonial period mission site located in west central Belize. Because of Tipu's unique position on the fringe of contact, it was arguably better insulated from consequences of contact, such as disruption of subsistence and trade patterns, that potentially resulted in nutritional stress than sites under direct Spanish control. However, the site was also a center for refugees escaping European domination to the north as well as a center for rebellion activities to the west. Therefore, a revised study of PH and CO was completed at Tipu using new, more widely accepted standards for the conditions. I expected to find four patterns: Tipu would have moderate rates of PH and CO compared with other Maya sites, severe lesions would be rare, and that nearly all lesions would be remodeled. I also anticipated that younger individuals would have higher rates of PH and CO, males will have higher rates of PH and CO than their female counterparts in general, as well as by age, and that higher status individuals buried in the nave, specifically closer to the altar, will have lower rates of PH and CO than those buried towards the back of the church and outside the church.

Most of my hypotheses were supported except for burial by status. I confirmed that, in general, Tipu has moderate rates of PH and CO among the Maya; they tended to run lower than Late Classic centers with higher population densities but were somewhat higher than those seen at other contact period sites. However, it must be observed that the conditions were generally very mild in most Tipu individuals in which they appeared, so this sub hypothesis was only partially supported. Only a small percentage scored even a moderate level of severity. Furthermore, all porosities were remodeled with no active cases seen among adults. I also observed that younger individuals had significantly higher rates of PH as well as higher rates of CO, although not significantly so, and males had significantly higher rates of PH compared to females. A variety of genetic, physiological, and cultural factors are likely in effect. My last hypothesis was rejected in that socioeconomic status, at least as reflected in burial location, does not appear to be correlated with rates of CO or PH. In fact, those with the lowest rates of both conditions were buried outside the church.

Overall, the basic research design appears to have been effective using the new standards put forth by Buikstra and Ubelaker (1994). Although a previous study did suggest that there were limitations to their application, specifically interobserver error (Jacobi and Danforth 2000), I felt confident in my ability to recognize various porosities associated with PH and CO by using the defining characteristics laid out in the standards as well as by applying the photos given in the text when scoring for presence. Furthermore, I did all scoring observations, so interobserver judgment did not come into play. I do think Jacobi and Danforth (2000) make a good point in that there need to be better definitions of each score as well as photos that display the range of what constitutes each score. After scoring for a while, I was easily able to score a 1, however I did need to use the standards when it came to a score of 2 or higher.

One of the shortcomings of the analysis was not a result of the methods used, but rather simply of the presentation of the conditions in the population. It is that very few individuals had lesions that would be considered very strong evidence of nutritional deficiencies. Instead, most PH and CO lesions were of a level that suggested the cases of deficiency were extremely minor, and likely did not have a marked impact on the lives of the individuals afflicted, and even others might not even have been PH, but rather impressions from other connective tissue attachments, such as Sharpey's fibers, that can at times appear (Powell 1985). Thus, the interpretation of the effects of the frequencies observed, especially when considered as simple presence/absence, may have been somewhat different than what was truly experienced by the inhabitants of Tipu.

In order to get a better understanding, I believe future studies should consider the conditions in all the subadults at Tipu using the new standards (Bianchi (2020) did score a subsample) to get the most comprehensive appreciation of health at Tipu, especially if correlations with other indicators, such as stature or LEH, are considered. As well, the individuals scored as having CO might be cross-checked with those who were determined to have scurvy (Gomberg 2018) to see the patterns that might emerge between the two indicators and how they were observed. I also believe that evaluation of PH and CO frequencies in those identified as locals and nonlocals at the site based on recent isotope data (Trask 2018) should be completed to get a better grasp on how the health patterns between the two groups might compare, especially whether the childhoods of those from outside Tipu indeed more stressed. I also believe stable isotope analysis, specifically C13 and N15, should be completed in order to better explore what the diet of those at Tipu. Exploring stable isotopes between childhood using teeth, and adulthood using bone, would give a better picture about how diet changes throughout life and demonstrate their influence on more general health indicators such as PH and CO. Finally, a study should be done to determine if there is a difference in how to determine if PH and CO are a result of vitamin B12 deficiency or folate deficiency should such analysis become possible in the future.

My research helps to shed light on the health at Tipu under the impact of Spanish colonization at the site, especially concerning its unique position on the fringe of contact and the impact refugees and rebellion may have had on the lives of those residing at the site. The findings can also be compared with those of other health indicators at Tipu to get a more comprehensive appreciation of the complicated interaction of health conditions that undoubtedly occurred. Furthermore, because of the new standards, the data for Tipu is now more comparable to current and future studies of PH and CO in other Maya populations. It will also continue to aid in the making of a more synergistic picture of what the life of the Maya may have looked like during the fateful period of European contact.

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