EPIPHYSEAL UNION OF THE VERTEBRAL RIB ENDS: A COMPARISON OF ARCHAEOLOGICAL AND MODERN POPULATIONS

By

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ABSTRACT

Epiphyseal Union of the Vertebral Rib Ends: A Comparison of Archaeological and Modern Populations

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Perhaps the most widely utilized post-cranial methods for aging sub adults and young adults are those that employ epiphyseal union to estimate age. The purpose of this study is to perform a test of the age estimation method established by Ríos and Cardoso (2009) which utilizes the epiphyseal union of the rib ends of modern subadults. The epiphyseal union of the vertebral rib ends occurs in stages that depend on the growth and development of subadults and adolescents. This progressive union can be used as a method, not only to create a population specific method for age estimation, but also to observe human development in past populations. I tested Ríos and Cardoso's method on 60 modern individuals from the Terry Collection at the National Museum of Natural History (NMNH), on 36 individuals buried at the New Kingdom site of Tell El-Amarna in Egypt, and on 19 individuals from Town Creek, a pre-historic North Carolina site. The ages of individuals at different stages of rib fusion at the Egyptian and Town Creek sites differed significantly from the Terry Collection data, as well as the Ríos and Cardoso sample. It was therefore necessary to construct population specific criteria for age estimation. Additionally, the individuals from Amarna demonstrated a delay in fusion of two years when compared to the Terry Collection, perhaps indicating that the young adults at Amarna experienced arrested growth. The presence of fluctuating bilateral asymmetry indicates environmental factors such as disease or poor nutrition to be the cause of the delay in development.

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INTRODUCTION

The most widely utilized post-cranial methods for estimating the age at death of sub adults and young adults use epiphyseal union to estimate age. Epiphyseal union occurs at sites of secondary ossification, and is crucial to the development of the juvenile skeleton. Epiphyses are slowly fused to the body of a developing bone. This fusion occurs at specific ages during childhood development. Thus, epiphyseal union is a measure of skeletal maturation. Advantages of using epiphyseal union methods include: narrow age ranges, simple scoring for the presence or absence of fusion, and consistency in maturation between populations (Cardoso 2008). However, most of the data collected on epiphyseal union has been conducted on epiphyses that fuse between 14-18 years of age.

The purpose of the Ríos and Cardoso (2009) study was to provide data on the epiphyseal union pattern of the vertebral rib ends, which is an area of study that has not been explored (Rios and Cardoso 2009). While İşçan and Loth (1984) studied the morphological changes in the fourth rib with respect to age, and McKern and Stewart (1957) observed the fusion of the head of the epiphysis, little research has been conducted on the secondary centers of ossification in ribs (Rios and Cardoso 2009). McKern and Stewart (1957) only observed fusion of the head of the epiphyses in white males under 17 (McKern and Stewart 1957). However, Ríos and Cardoso believed that a more systematic study needed to be conducted of not only fusion and the head of the epiphyses, but also at the articular and non-articular tubercles. Furthermore, they wished to study the fusion in these three locations, in all 12 ribs on each side (Ríos and Cardoso 2009). According to Ríos and Cardoso (2009), the study of the stages of union of the vertebral epiphyses of the ribs can provide accurate age estimates for individuals aged 11-27 (Cardoso 2008). In this thesis, their method is tested on a modern sample in order to determine the utility of using this approach for age estimation.

The Terry Collection (National Museum of Natural History), the modern sample used in this blind test of the age estimation method, is very similar to the Lisbon Collection used in the Ríos and Cardoso 2009 study. The collections both date to the early 19th century and contain individuals of a lower socioeconomic status (SES). While the comparison of these two populations certainly proved the utility of this age estimation method on modern populations, the similarity of the populations led to very similar results. In order to assess the utility of the age estimation method established in Rios and Cardoso on all populations, their method was tested on two archaeological samples. For both of these archaeological populations, the results were significantly different than the modern Terry sample.

In this thesis, I discuss the differences in the results of this age estimation method between archaeological and modern populations, and outline two hypotheses to explain these differences. The first hypothesis is that environmental stress is impacting the growth and development of individuals in each of the populations. Environmental stress can be defined as any outside influence on the health of an individual. Some examples of environmental stress include: poor nutrition, hard labor, and disease. These stressors can sociocultural and not the result of a harsh physical environment. The second hypothesis is that difference in ages of fusion is the result of a sample bias, which occurs when some individuals in the population are less likely to be included in the sample analyzed than others. In an archaeological context, sample bias must always be considered, because it is impossible to find or analyze entire populations. According to Scheuer and Black (2004), age estimation methods are dependent on the population health, nutrition, and other environmental factors (Scheuer and Black 2004). If environmental stress is the cause of the discrepancies in the age estimations provided by the vertebral rib end method, then according to Ríos and Cardoso, the data should show bilateral asymmetry between the left and right ribs in two archaeological samples.

Chapter 1

METHODS AND SAMPLES

Details of the Ríos and Cardoso Method

In their 2009 publication in the *American Journal of Physical Anthropology*, Ríos and Cardoso established a scoring system as well as data for the age ranges they correspond to their scoring system. Additionally, the presence /absence of the articular and non-articular tubercles were observed.

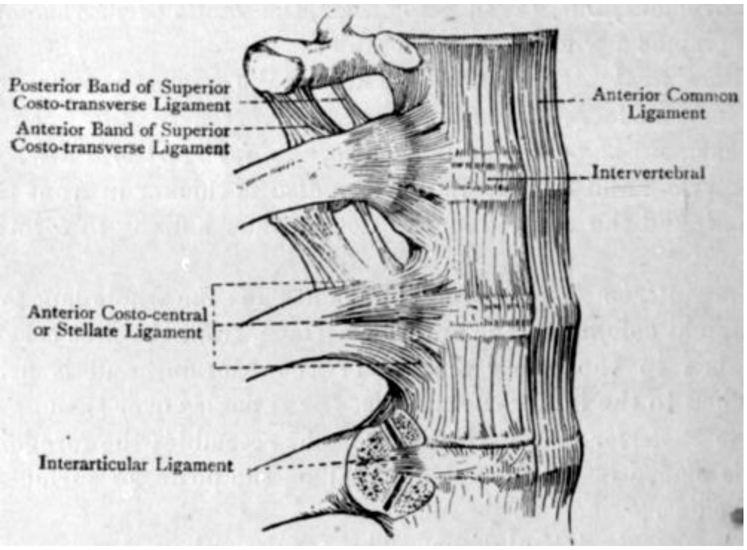

Figure 1 – Drawing of the anatomy of the thoracic region (Marieb and Hoehn 2008)

In order to use the scoring system of Ríos and Cardoso, one needs to have a working knowledge of the functional anatomy of the vertebral end of the rib. The ribs articulate with the vertebrae at the costovertebral joints, where the head of the rib and the lateral facet of the vertebral body meet. Additionally, the articular tubercle of the rib, and the transverse process of the vertebrae also articulate. The costo-central ligament, which holds the costal neck and the articular tubercle, also binds the non-articular tubercle to the transverse process of the vertebrae (Figure 1). Therefore, the lower ribs, which are associated with vertebrae which do not have transverse processes, do not have tubercles (Marieb and Hoehn 2008). Additionally, ribs 2-6 show torsion at the ventral extremity and the outer surface is oblique upwards. The lower ribs 7-10 have a deeper subcostal groove posteriorly. The primary centers of ossification appear first in ribs 5-7 in the posterior angle between the eighth and ninth weeks of prenatal life (Scheuer and Black 2004). The ribs commence ossification before the corresponding vertebrae, thus the rib end development is independent of the vertebrae development. There is little information on the development of the secondary centers of ossification, from either clinical data or osteological material. However, Scheuer and Black (2004) explain that the first rib tubercles are closely related by proximity and therefore form as one tubercle. In ribs 2-12, the tubercles form separately and at different times. The head epiphysis appears as a node of bone in the superior articular facet and then spreads downwards into the inferior facet. Furthermore, upper and lower ribs mature faster than middle ribs. This distinction is important because the analysis of ribs requires a method specific to each rib, not in general.

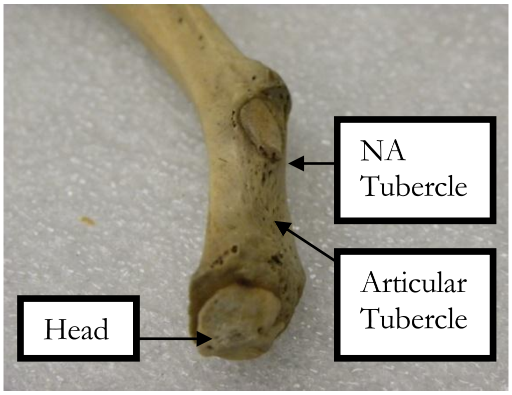

Figure 2 – Location of the secondary centers of ossification

Figure 3 – Rib seriation

According to Ríos and Cardoso, epiphyses are found in three places on the ribs, the head, the articular tubercle, and the non-articular tubercle, as shown in figure 2. The first step in the evaluation of each individual was to side each rib, and then to determine the rib number by seriation (Rios and Cardoso 2009). In order to seriate the ribs, the 1st, 2nd, and 12th ribs were first identified and placed in order (Figure 3). I noted that ribs closer to the first rib had a greater angle and were generally more curved and narrow. Ribs that were closer to the bottom became increasingly bladelike and broad. Additionally, the lower ribs tended to have a flared head, while upper ribs heads tended to be more uniform and vertical (Scheuer and Black 2004).

Figure 4 – Stage 1 Fusion at the articular tubercle and the head

Figure 5 – Stage 2 fusion at the head

After the ribs were identified by side and number, the presence or absence of the articular and non-articular tubercles was recorded. Then, the degree of fusion was scored: “1- no union; 2- partial union; 3-completed union” (Rios and Cardoso 2009). Figures 4-6 show the three stages of fusion. Figure 5 shows the lack of union of the head and articular epiphyses on the left first rib of an 18 year old white male. Stage 1 is characterized by billowing on the metaphyseal surface of the site of ossification. This morphology indicates the grooves left by the extensive vasularity of the region as bone formation is related to a blood supply (Scheuer and Black 2004).

Figure 5 shows the partial fusion of the head and articular tubercle epiphyses on the 8th left rib of an 18 year old white male. In order for fusion to be scored as a stage 2, the epiphyses must be only partially fused, and show space in between the surface and the epiphyses. Figure 6 is an example of stage 3 or complete fusion as shown on the 1st ribs of a 24 year old black male. Stage 3 requires that the epiphyses are completely fused. However, it should be noted that at stage 3, an epiphyseal scar may remain. This scar line may be confused with incomplete fusion. Ríos and Cardoso also added a stage 2b, which could only be scored for the head epiphyses. Stage 2b describes head epiphyses which are only fused around the perimeter, but not in the center. Therefore, there is a ring of incomplete fusion in the center of the head. As explained by Ríos and Cardoso, for each individual, the ribs from each side were each scored independently of one another. In other words, the left and right ribs from each side were scored separately.

Figure 6 – Stage 3 fusion for two first ribs

The Terry Collection

The Terry collection is comprised of mostly lower income individuals whose bodies were either donated to the state of Missouri or not claimed. The cadavers were obtained from St. Louis Hospital or from morgues, and all medical records and death certificates were preserved. The date of birth of the Terry Collection individuals ranges from 1822-1943. All individuals were autopsied, and it was not uncommon for the ribs to be cut mid-shaft in order to access the internal organs (Hunt 2010). In this study, 29 of the 60 individuals observed showed evidence of cut marks on the ribs or ribs that were cut through cleanly. The ribs most commonly cut were ribs 4-8. The Terry Collection houses only a few individuals between the ages 14-18 years of age at death. For the purposes of this thesis, this is problematic, because it creates a sample bias. The individuals of younger ages have a greater impact on the results than the individuals above 18. The Terry Collection was chosen as the sample for the blind test because there are medical records listing age and sex for each of the individuals.

Amarna Sample

The 36 individuals analyzed in this thesis from the Amarna excavations were buried in a cemetery 2 km from the city Akhentaten. The city was built as the new capital of the Pharaoh Akhenaten, dedicated to his new religion of worship to the Aten. Construction started in or around Year 5 of his reign (1346 BCE) and was probably completed by Year 9 (1341 BCE), although it became the capital city two years earlier. The city was abandoned after the death of Akhenaten in 1336 BCE. Therefore, the site could only have been occupied for at most 15 years. There were two cemetery spaces near the city, the noble's cemetery (North Tombs Cemetery), and the commoner's cemetery (South Tombs Cemetery) (Rose, Kemp, and Zabecki 2008). The short occupation of the site allows for a snapshot of what life was like for Egyptians during a time of great upheaval and unrest in the empire. The pharaoh Akhenaten dedicated many stele and wall paintings to the description of life in his new city. In

Figure 7 – Map of Egypt showing Amarna

particular, the 14 known boundary stelae imply that the Aten will protect the city and that food would be abundant and life would be fulfilling. A quote from Akhenaten derived from the stela texts says the same "Behold, fill Akhetaten with provisions - a storehouse for everything" (Murnane 1995). He describes abundance and opulence, and wrote that his people under his rule were healthy and well provisioned (Rose, Kemp, and Zabecki 2008).

There is further evidence in the archaeological record at the site supporting the described abundance during Akhenaten's rule. The Great Aten temple, which is located opposite the Great Palace in the northern sector of the Central City, is an intimidating structure spanning 730m in length and 229m in width (Rose, Kemp, and Zabecki 2008) . Within the temple is evidence for over 750 stone offering tables and an additional 920 more offering tables outside the temple, but within the walls (Kemp 1994). Further evidence can be found within several of the nobles' tombs. Wall reliefs in the tombs of Meryra and Panehsy, both senior priests in the temple, show the Great Aten Temple with the offering tables piled high with food of all kinds. These tomb scenes imply a city of abundance with huge quantities of food offered to the Aten, before it was distributed to the officials and general populace (Kemp 2006).

However, biological and archaeological analysis at Amarna has cast doubt onto Akhenaten's portrayal of his city and its bounty. In 2002 the commoner's cemetery at Tell El-Amarna was discovered (Rose, Kemp, and Zabecki 2008). Since excavation began in 2006, 194 individuals from the cemetery have been recovered. Osteological analysis by Jerome C. Rose and Melissa Zabecki has shown that there is an abnormally high rate of adolescent deaths at Tell El-

Amarna, when compared to childhood or adult deaths. This unusual pattern indicates a high level of environmental stress on these individuals, which is most likely the result of poor diet and disease (Rose, Kemp, and Zabecki 2008). Rose and his coworkers evaluated femur length for the individuals buried at the commoner's cemetery. In order to discern whether childhood health improved or deteriorated during the time of Akhenaten, they calculated adult heights for those over 35 years of age who would have matured long before Akhenaten reign began and those younger than 35 years who could have achieved adult height during some portion or just before Akhenaten's reign. Their results showed that the pre-Akhenaten males who matured before moving to Amarna are 164.2cm, compared to 162.1cm for those who matured during Amarna times. Similarly, the older females are taller at 154.4cm than the younger females at 150.9cm. The data suggest that the conditions of childhood stress worsened just before and during the reign of Akhenaten (Rose, Kemp, Zabecki 2008). The discrepancy between the descriptions offered by the boundary stelae and the tomb walls needs to be reconciled with the biological data. It is therefore necessary to gather as much information as possible about the lives of the everyday inhabitants of Akhentaten in order to ascertain the truth of Akhenaten's accounts. Therefore, all of the individuals analyzed for the purpose of this thesis were recovered from the commoner's cemetery.

Town Creek Sample

Town Creek Indian Mound has been the focus of extensive archaeological investigation since 1937, when the site was acquired by the state of North Carolina. The individuals analyzed in this thesis were buried around the site, which included the palisaded village, with

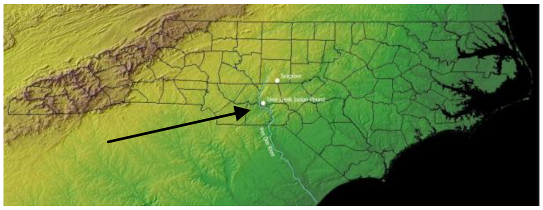

Figure 8 – Map of Town Creek Site in Modern North Carolina

exception to the area immediately around the mound. One-hundred-fifty-five human burials were excavated during archaeological investigation of the village area at Town Creek, and they were dated to the primary Pee Dee phase (1200-1400 CE)(Davis et al. 1998). The collection is stored at the Research Laboratories of Archaeology at the University of North Carolina at Chapel Hill.

Joffre Coe analyzed 5 individuals from Town Creek in order to investigate the differences in how the Pee Dee people (individuals analyzed in this thesis) and the Siouan people lived (Coe et al. 1995). These case studies do not provide conclusive data to support population wide generalizations, however, they do uncover some of the individual life histories of these individuals. For example, burial 42 consists of the skeleton of a young female with complete adult dentition, showing only slight wear on the 3rd molars. Coe estimates her age based on dentition to be about 21 years of age (Coe et al. 1995). However, there was no attachment of the distal epiphyses of the tibia and fibula, and in addition, there was incomplete fusion of the iliac crest of the os coxae. Her age at death as estimated by epiphyseal union was under 16. According to Coe, the non-fusion of the epiphyses has implications in regard to her health. He mentions that this individual's cranium showed evidence of porotic hyperostosis and cribra orbitalia. In addition, Coe states that the growth of this female's maxillary canines was effected, as evidenced by enamel hypoplasias. Radiographic analysis of this individuals long bones showed Harris lines (horizontal lines of calcification that indicates a disruption in growth) between two age ranges 4-5 and 9-10. Coe ultimately concludes that the most likely cause of disagreement between the dental and skeletal age estimates is a moderately retarded puberty. He goes on to state that a delay in the onset of puberty can be caused by several conditions including, malnutrition, endocrine imbalance, and metabolic abnormalities (Coe et al 1995). Coe however, does not address that the bilateral symmetrical delay in fusion may be the result of genetic factors, because his sample size is too small.

In order to better assess the delay in fusion at Amarna, the Town Creek sample was chosen as the comparative archaeological sample. The analysis of another archaeological sample increased the number of samples, thus minimizing the effects of sample bias. In addition, the individuals from Town Creek have some similar indicators of environmental stress as seen in the Amarna sample.

Chapter 2

MODERN SAMPLE AND TEST

Sample Description

This chapter details a blind test of the age method established by Ríos and Cardoso. The skeletal remains of 60 individuals of known age, sex, and ancestry were selected from the Terry collection at the National Museum of Natural History. The sample was selected randomly from the catalog of the Terry collection of individuals aged 14-27. The lower age limit was established by the youngest individual in the Terry collection (14 years of age). The upper limit (27 years of age) was chosen because of time constraints, and more importantly, the absence of epiphyseal union observed by Ríos and Cardoso in individuals older than 27.

Results

As seen in table 1, the articular tubercle first begins to fuse earliest around the 10th rib, until it is completely absent by the 12th rib. Ríos and Cardoso began to notice the decline in percentages of present articular tubercles in the 8th rib (Rios and Cardoso 2009). In ribs 8-11 it is very difficult to tell whether or not the articular tubercle is present, which may account for this discrepancy.

Table 1- Presence/Absence of Articular Tubercle (both sexes)

Rib Number	1	2	3	4	5	6	7	8	9	10	11	12
% Present	100	100	100	100	100	100	100	100	100	87	26	0
% Absent	0	0	0	0	0	0	0	0	0	13	74	100

The presence of this tubercle increases from the 1st to the 5th rib and decreases from the 6th to the 12th rib. Again, this result is very similar to the observations of Ríos and Cardoso. As seen in table 2, the non-articular tubercle is present from the 2nd rib to the 9th rib. Unlike the articular tubercle, the non-articular tubercle gradually increases and then decreases in frequency.

Table 2 –Presence/Absence of Non-articular Tubercle (both sexes)

Rib Number	1	2	3	4	5	6	7	8	9	10	11	12
% Present	0	87	93	96	100	98	83	43	7	0	0	0
% Absent	100	13	7	4	0	2	17	57	93	100	100	100

Aging Method Results:

Each rib was assessed for fusion at the head, the articular tubercle, and the non-articular tubercle as described in the materials and methods section of this paper. Then, based on those results, each rib was assigned an age range based on the values provided by Ríos and Cardoso. However, since an age range for the individual is desired, not an age range for an individual rib, the age ranges for each rib must be taken into consideration when estimating the overall age range of an individual. Therefore, the minimum age must represent the youngest age possible for the individual, and therefore the youngest age estimated by each of the rib ranges. For example, if the rib 1 range was 16-21 and the rib 2 range was 11-21, then the overall age range for the individual would be 11-21. This is also true for the maximum age, which must represent the oldest possible age for that individual. This method yields extremely large ranges of possible ages (average width of range 13.15 years). One result of these extremely wide age ranges is that this method has a percent accuracy of 100 percent; however, the utility of such wide ranges must be questioned. The ages of all of the 60 individuals studied fit within the age ranges predicted by this method. Table 3 shows the catalog age of the individual, the estimated age range, and whether or not the actual age was predicted by the age range for 27 of the 60 individuals. This table demonstrates how the accuracy of the method was determined.

Table 3- Age ranges including all three loci from the Terry Collection

Cat #	Age from Death Certificate	Age Range Est.	Age w/In range
1363	14	11--24	yes
822	16	11--27	yes
306	17	11--23	yes
579	17	11--22	yes
960	17	11--21	yes
335	18	16-22	yes
740R	18	11--21	yes
800R	18	11--23	yes
90	18	11--21	yes
1434R	19	11--27	yes
1591	19	11--27	yes
457	19	11--24	yes
760	19	11--27	yes
567	19	11--23	yes
1023	20	11--21	yes
1183	20	11--27	yes
210	20	11--22	yes
222	20	11--27	yes
929	20	11--27	yes
1032	21	11--27	yes
1187	21	11--21	yes
203	21	11--22	yes
377	21	11--27	yes
970	21	11--27	yes
561	22	11--23	yes
39	22	11--27	yes
940	24	11--27	yes

However, because the Terry Collection population is on average older than the population observed by Ríos and Cardoso, the minimum age estimate of 11 years is too low. The first epiphysis to fuse is the non-articular tubercle. Using their method, if rib 7 shows stage 3 fusion, then that individual must be over 11 years old. Therefore, the minimum age in the age range must be 11, even if that individual has completely fused in the other two loci as well. Therefore, in this population, observing the fusion of at the head, which is the last to fuse, provided much narrower age ranges (on average 8.04 years), and still had a high percent accuracy (96.3%). Table 4 shows the resultant age ranges when only the head was considered for 27 of the 60 individuals.

Table 4- Age ranges from Head only

Cat #	Age from Death Certificate	Age Range Head Only	Age w/in range
1363	14	15-24	no
822	16	15-27	yes
306	17	15-23	yes
579	17	16-22	yes
960	17	16-21	yes
335	18	16-22	yes
740R	18	16-21	yes
800R	18	15-23	yes
90	18	16-21	yes
1434R	19	15-20	yes
1591	19	17-27	yes
457	19	15-24	yes
760	19	16-27	yes
567	19	15-23	yes
1023	20	16-21	yes
1183	20	17-27	yes
210	20	16-22	yes
222	20	17-27	yes
929	20	15-27	yes
1032	21	17-27	yes
1187	21	16-22	yes
203	21	16-22	yes
377	21	20-27	yes
970	21	17-27	yes
561	22	17-23	yes
39	22	15-27	yes
940	24	17-27	yes

These age ranges are much more meaningful than the ranges provided from observation of all three loci, because, the age ranges are much narrower if the observer chooses one rib (the most represented rib in the sample), which also reduces the time it takes to perform the method.

Overall, individuals aged 14-16 showed stage 1 and stage 2 fusion at the head, and either stage 2 or stage 3 fusion at the tubercles. Individuals aged 17-20 tended to show stage 2 fusion at the head and stage 3 fusion at the tubercles. In the age range 21-24 individuals showed stage 3 fusion everywhere, with the exception of three individuals who showed stage 2b fusion. The 2b fusion was observed on the 8th and 10th ribs of these individuals (2 male, 1 female).

While assessing the validity of the Ríos and Cardoso age ranges by percent accuracy provides meaningful information, it is also necessary to investigate possible sex differences in the maturation of the tubercles. A chi square analysis was performed on the Terry Collection sample in order to determine if the results for females were different from males, when compared to two variables, fusion or no fusion. This differentiation would suggest a difference in the age of rib maturation between the sexes. This question of sexual differentiation is critical to this thesis, because any comparison of the populations would average the results across the sexes, since the archaeological samples were too small to be compared by sex. The results show that for the majority of the ribs, there was significant sex differentiation. All of the p values are below 0.05 and these results are consistent with Ríos and Cardoso.

Table 5 – Chi square and p values for selected ribs

Rib Number	1	2	3	4	5	10	11
χ^2	8.02042	7.867	5.79724	6.99581	7.35476	11.5236	8.51453
P	0.00989	0.02586	0.04196	0.032166	0.02362	0.00489	0.008254

Discussion and Conclusion


Figure 9 – incomplete epiphysis

Ríos and Cardoso's method depends on the consistency and accuracy of numbering the ribs. This can be extremely difficult in situations where several ribs are missing, or as in the Terry sample, where the ribs were cut during autopsy. The age ranges provided in the method are rib specific, and therefore, if two ribs are incorrectly numbered it can change the resultant age range dramatically. Furthermore, it can be challenging to tell the stage 1 and stage 3 fusion apart from one another. Therefore, the most useful and accurate information about rib maturation is obtained from ribs showing stage 2 fusion, which is easy to identify, and less likely to be rib specific.


Figure 10 – spur on non-articular tubercle

Articular and Non-articular Tubercles:

The observations from the study on the presence/ absence of the articular and non-articular tubercles agree with the data from the Ríos and Cardoso (2009) study. As predicted, the articular and non-articular tubercles become increasingly absent in the lower ribs (particularly 11 and 12). It is interesting that the non-articular tubercle disappears earlier than the articular tubercle. While the absence of the articular tubercle is a result of the loss of articulation with the transverse process of the vertebrae, the presence of the non-articular tubercle increases to rib 5 and decrease to rib 12. It does not have the same correlation to the presence of the transverse process. Therefore, its presence or absence must be determined by the costotransverse ligament strength. The most mobility is needed in the thoracic region, which corresponds to the middle ribs.

In some cases, a common epiphysis was observed for ribs 2-4, which made it difficult to distinguish a lack of non-articular tubercle from the two tubercles. In figure 9, the articular tubercle epiphysis does not completely cover the tubercle, but this rib was still scored as stage 3 because the epiphysis was completely fused, with no space underneath it. In figure 10, the non-articular tubercle might be scored as a stage 2, but the object pointing out of the tubercle is a spur not an epiphysis. Spurs can be recognized because they generally on have space underneath them and one end, and they are irregularly shaped. Most tubercle epiphyses are round, and if their fusion is not complete, they will have space underneath them around most of their circumference.

Figure 11 – Epiphyseal scar

Head Fusion:

In this sample, all individuals that were 22 or older showed complete fusion of the head (stage 3) for at least nine of the twelve ribs. The youngest individual who showed partial fusion in the head (stage 2) was 14. Figure 11 shows a rib with an epiphyseal scar on the head. Ribs with these scars are particularly difficult to score and consequently to age. In this study, ribs that had these scars were scored at stage 3 fusion, just as Ríos and Cardoso scored them in their study. The youngest individual in this study to have one of these scars on their at least one of their ribs was 19, and the oldest was 24.


Figure 12 – incomplete epiphyses

Generally, individuals with stage 2 fusion at the head had narrower estimated age ranges than individuals who showed either stage 1 or stage 3 fusion. This is because the age ranges assigned by Ríos and Cardoso to stage 2 fusion in the head are much more specific, and the minimum age is higher because most of these individuals showed stage 2 or 3 fusion in the tubercles.

Another interesting observation was that in the ribs of younger individuals (age 14-18), the heads of the epiphyses often did not cover the entire surface of the head. As shown in figure 12, this characteristic occurred in all of the ribs in an individual if it occurred at all.

A general trend of earlier fusion of the head of the first and last ribs was observed. Most of the individuals showed a more advanced stage of fusion in the 1st rib (90%) than in the 4th,5th, and 6th ribs. Additionally, around 95% of the individuals had more advanced union in the 11th and 12th ribs compared to the 4th, 5th, and 6th ribs. This is consistent with the results of McKern and Stewart (1957) and Ríos and Cardoso (2009).

Conclusion:

The Ríos and Cardoso age method using the epiphyseal union at the vertebral rib ends can be successfully used to establish age ranges for young adults in the Terry Collection sample. However, some limitations to this method include: difficulty numbering the ribs, confusion between fusion or no fusion in the tubercles, and large age ranges. As seen in the Terry Collection sample, observing the epiphyseal union of the head alone provides much narrower age ranges and only a small reduction in accuracy. The age ranges estimated in this method for aging are equal to or narrower than age ranges for young adults provided by methods such as union at the iliac crest, radius, and humerus. The best results were obtained from individuals who had ribs with stage 2 fusion, most specifically, stage 2b. Overall, this age method is limited by the fact that age ranges are assigned to individual ribs, and therefore, the age range for the individual must account for the minimum and maximum possible ages as determined by the rib ranges. In order for the method to be useful in a forensic or archaeological context, the method needs to be revised so that the scoring system does not focus on individual ribs, but instead on those ribs which exhibit stage 2 and 3 fusion.

Chapter 3

EPIPHYSEAL UNION OF THE VERTEBRAL RIB ENDS FOR THE TWO ARCHAEOLGICAL SAMPLES

Amarna

The skeletal remains of 36 individuals buried at the New Kingdom site of Tell El-Amarna were evaluated in this study. All individuals were cleaned by dry brushing. Age and sex estimates were made using the protocols of Buikstra and Ubelaker (Buikstra and Ubelaker 1994).

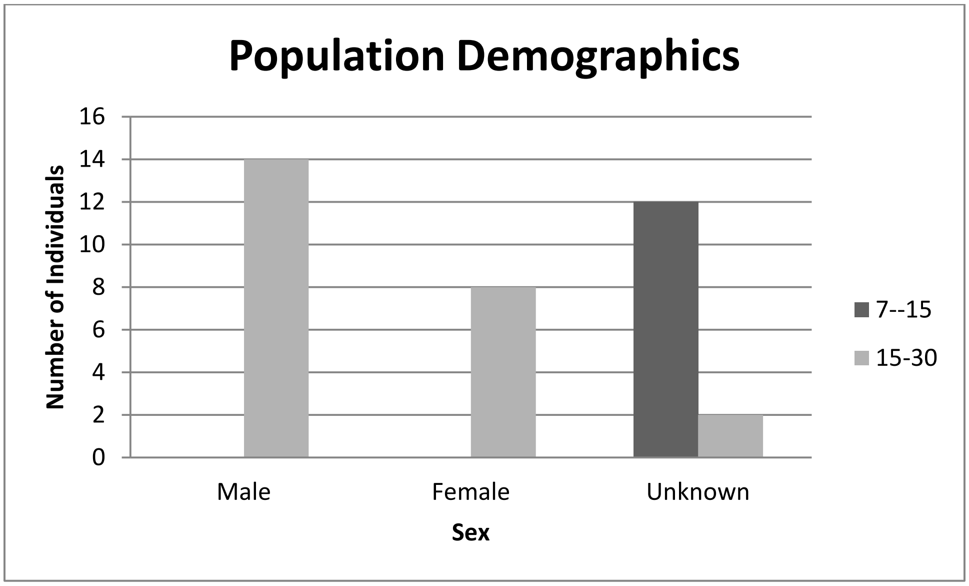

Figure 13 – Sample Demography at Amarna

For the purpose of the bioarchaeological analysis of the Amarna Project, individuals have been placed into age ranges (by Jerome C. Rose) based on patterns observed in the growth and development of the population as a whole, and major changes in life activities. For example, children ages 7-15 performed similar domestic roles (Rose, Kemp, and Zabecki 2008). In this study, two of these age range are important: 7-15 and 15-25. Individuals aged 7-15 are considered juveniles and therefore sex was not estimated. Individuals whose sex could not be estimated, but whose age could be estimated were placed in the 7-15 group regardless of their age. These individuals were analyzed separately and were not included in the study of sex differences in age at fusion. Individuals aged 15-25 are young adults and sex was estimated using the ventral arc, subpubic concavity, and subpubic angle as described by Phenice (1969), and Buikstra and Ubelaker (1994) (Phenice 1969; Buikstra and Ubelaker 1994). These individuals were analyzed separately by sex.

Aging Method Results:

After assigning age ranges based on the tables in Ríos and Cardoso it became clear that the Amarna population showed protracted (wider age ranges) as well as later fusion compared to the published Portuguese sample. Therefore, it was necessary to create population specific ranges based on the data collected. This was accomplished by recording the age estimates (from dental age) produced for each individual in the sample (who also provided an age estimate for each rib), which were obtained from the Amarna catalog of osteological material. Then, the stage of fusion data was divided into three groups: male, female, and individuals without a sex estimate. These three groups were further divided by site of ossification. For example, all of the head fusion data from ribs belonging to males were observed by rib number (1-12). Then, for each stage of fusion (1-3), the age estimates for the ribs (from the individual's age estimate) were recorded. This process produced age ranges for each stage of fusion, specific to sex and site of ossification, that reflected the age estimates for the individuals. These ranges could be applied to age individuals from Amarna in the future. The following tables summarize the data collected for the 2010 field season as well as the previous years of excavation. Each rib is counted as an individual observation (n=1).

Table 6- Age Ranges for Head Fusion (Males 15-25)

Rib Number	Stage 1	Stage 2	Stage 3	Stage 2b
1	16-22 (n=9)	18-24 (n=8)	20-25 (n=2)	
2	15-22 (n=6)	16-24 (n=13)	20-25 (n=2)	
3	15-22 (n=7)	16-25 (n=16)	—	
4	15-22 (n=11)	16-24 (n=14)	20-25 (n=1)	
5	15-22 (n=13)	16-24 (n=7)	20-25 (n=1)	
6	15-22 (n=14)	16-24(n=7)	20-25 (n=1)	
7	15-22 (n=12)	16-24 (n=7)	20-25 (n=1)	
8	15-22 (n=11)	16-24 (n=9)	20-25 (n=2)	
9	15-22 (n=11	16-24(n=9)	—	20-25 (n=1)
10	15-22 (n=6)	16-24 (n=16)	—	20-25 (n=1)
11	15-20 (n=4)	16-24 (n=15)	20-25 (n=2)	
12	15-20 (n=2)	16-24 (n=17)	20-25 (n=2)	

Table 7- Age Ranges for Articular Tubercle Fusion (Males 15-25)

Rib Number	Stage1	Stage2	Stage3
1	18-20 (n=2)	15-18 (n=2)	16-25 (n=18)
2	15-20 (n=4)	15-18(n=4)	16-25 (n=18)
3	15-20 (n=6)	16-24 (n=3)	16-25 (n=18)
4	15-20 (n=6)	16-20 (n=5)	16-25 (n=15)
5	15-20 (n=6)	16-22 (n=5)	16-25 (n=15)
6	15-20 (n=6)	16-22 (n =8)	17-25 (n=11)
7	15-20 (n=4)	15-24 (n=10)	17-25 (n=11)
8	15-20 (n=6)	16-18 (n=4)	16-25 (n=18)
9	15-20 (n=5)	16-24 (n=5)	16-25 (n=16)
10	15-20 (n=5)	16-22 (n=4)	16-25 (n=13)
11	—	—	—
12	—	—	—

Table 8- Age Ranges for Non-Articular Tubercle (Males 15-25)

Rib Number	Stage1	Stage2	Stage3
1	—	15-16 (n=1)	16-25 (n=18)
2	—	15-20 (n=5)	16-25 (n=16)
3	15-16 (n=1)	15-20 (n=4)	16-25 (n=19)
4	15-16 (n=1)	15-20 5(n=7)	16-25 (n=17)
5	15-16 (n=1)	15-20 (n=4)	16-25 (n=16)
6	—	15-20 (n=6)	16-25 (n=17)
7	18-20 (n=1)	15-20 (n=4)	16-25 (n=17)
8	18-20 (n=1)	15-20 (n=5)	16-25 (n=12)
9	—	15-16 (n=1)	18-24 (n=2)
10	—	—	—
11	—	—	—
12	—	—	—

Table 9- Age Ranges for Head Fusion (Females 18-30)

Rib Number	Stage1	Stage2	Stage3
1	—	18-25 (n=5)	20-30 (n=7)
2	20-22 (n=1)	18-25 (n=6)	20-30 (n=6)
3	—	18-25 (n=7)	20-30 (n=6)
4	—	18-29 (n=7)	20-30 (n=7)
5	—	18-29 (n=8)	20-30 (n=7)
6	—	18-29 (n=8)	20-30 (n=4)
7	—	18-29 (n=9)	20-30 (n=4)
8	18-19 (n=1)	18-29 (n=6)	20-30 (n=3)
9	—	18-29 (n=10)	20-30 (n=3)
10	—	18-29 (n=7)	20-30 (n=4)
11	—	18-29 (n=8)	20-30 (n=4)
12	—	18-22 (n=5)	20-30 (n=3)

Table 10- Age Ranges for Articular Tubercle Fusion (Females 18-30)

Rib Number	Stage1	Stage2	Stage3
1	—	—	18-30 (n=12)
2	—	20-22 (n=1)	18-30 (n=12)
3	—	—	18-30 (n=12)
4	—	—	18-30 (n=13)
5	—	18-20 (n=1)	18-30 (n=1)
6	—	—	18-30 (n=10)
7	—	—	18-30 (n=12)
8	—	18-25 (n=2)	18-30 (n=7)
9	—	18-25 (n=2)	18-30 (n=9)
10	—	—	18-30 (n=4)
11	—	—	20-29 (n=1)
12	—	—	—

Table 11 – Age Ranges for Non-Articular Tubercle Fusion (Females 18-30)

Rib Number	Stage1	Stage2	Stage3
1	—	—	18-30 (n=12)
2	—	—	18-30 (n=13)
3	—	—	18-30 (n=12)
4	—	—	18-30 (n=13)
5	—	—	18-30 (n=13)
6	—	—	18-30 (n=11)
7	—	—	18-30 (n=10)
8	—	—	20-30 (n=5)
9	—	—	20-30 (n=4)
10	—	—	23-30 (n=1)
11	—	—	—
12	—	—	—

Table 12 – Age Ranges for Head Fusion (7-15 or without sex estimate)

Rib Number	Stage1	Stage2	Stage3
1	7-20 (n= 16)	—	—
2	7-15 (n=17)	—	—
3	7-15 (n=14)	—	—
4	7-15 (n=16)	—	—
5	7-20 (n=14)	—	—
6	7-20 (n=14)	—	—
7	7-20 (n=11)	—	—
8	7-20 (n=18)	—	—
9	7-20 (n=24)	—	—
10	7-20 (n=22)	—	—
11	7-15 (n=20)	15-20 (n=4)	—
12	7-14 (n=20)	15-20 (n=4)	—

Table 13 – Age Ranges for Articular Tubercle Fusion (7-15 or without sex estimate)

Rib Number	Stage1	Stage2	Stage3
1	7-14 (n=15)	15-20 (n=1)	15-20 (n=3)
2	7-15 (n=16)	15-20 (n=2)	15-20 (n=2)
3	9-15 (n=12)	15-20 (n=1)	15-20 (n=1)
4	7-15 (n=15)	15-20 n=1)	15-20 (n=1)
5	9-15 (n=12)	15-20 (n=4)	—
6	7-15 (n=12)	15-20 (n=4)	—
7	7-14 (n=9)	15-20 (n=4)	—
8	7-15 (n=17)	15-20 (n=4)	—
9	7-15 (n=18)	15-20 (n=6)	—
10	7-15 (n=12)	15-20 (n=2)	15-20 (n=2)
11	9-14 (n=3)	—	—
12	—	—	—

Table 14 – Age Ranges for Non-Articular Tubercle Fusion (7-15 or without sex estimate)

Rib Number	Stage1	Stage2	Stage3
1	7-14 (n=13)	—	12-20 (n=5)
2	9.5-15 (n=8)	—	12-20 (n=5)
3	9.5-15 (n=8)	—	15-20 (n=2)
4	7-15 (n=14)	—	15-20 (n=2)
5	9-15 (n=12)	—	15-20 (n=2)
6	7-15 (n=9)	—	15-20 (n=4)
7	7-14 (n=6)	—	15-20 (n=4)
8	7-14 (n=8)	—	15-20 (n=4)
9	9-14 (n=2)	—	—
10	13-14 (n=1)	—	—
11	—	—	—
12	—	—	—

In all three groups (male, female, or with no sex estimate), the articular tubercle age ranges are the narrowest, and therefore the most useful for estimating age. For younger individuals the non-articular tubercle provides the second narrowest age range, whereas for adults the head is the second most useful location.

Sex Differences:

The individuals from Amarna show statistically significant sex differences in fusion at the head epiphysis. A chi-square test was used for the analysis and the χ^2 and P values are listed for ribs 1-5 and 10-11 below. Some ribs do not show significant differences (with probability values above 0.05); however, this is most likely due to the small sample size.

Table 15 – Chi square and p values for selected ribs

Rib Number	1	2	3	4	5	10	11
χ^2	7.02035	6.667	4.77273	4.88471	7.32912	10.3527	2.9322
P	0.02989	0.03567	0.09196	0.08696	0.02562	0.00565	0.23082

The articular and non-articular tubercles do not show statistically significant sex differences. It is possible that more data is needed. It should be noted that Ríos and Cardoso also found that the articular and non-articular tubercles did not show sex differentiation.

Conclusions:

The individuals at Amarna showed a marked difference in fusion that will be examined further in Chapter 5. Rib fusion at Amarna was easy to categorize into the three stages, and the preservation was excellent. Despite the difference in fusion between this data and the age ranges provided by Rios and Cardoso, the population specific charts created as a part of this research would be an accurate method to estimate age at Amarna.

Town Creek

From the Town Creek collection, 19 individuals were chosen based on the completeness of the remains and age. The procedure for analysis described in chapter 1 was used to create age estimates for the population. Sex estimates for this sample were obtained from the NAGPRA Inventory Catalog (Davis et al. 1998).

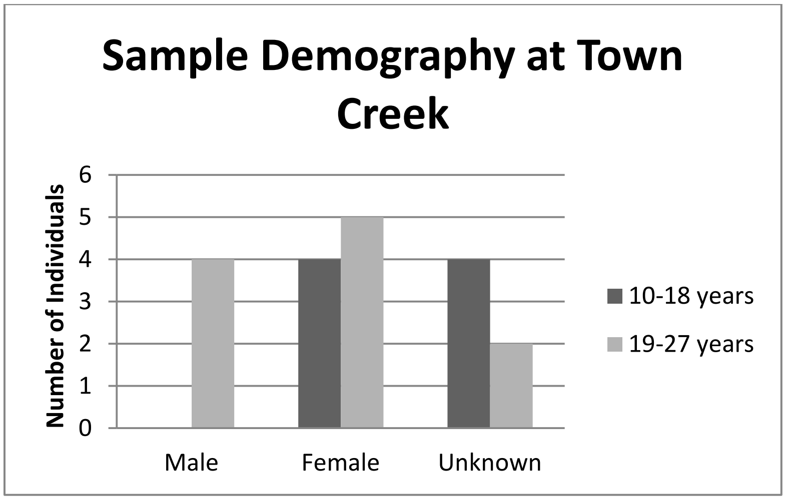

Figure 24 – Sample Demography at Town Creek (note: individuals with ages estimated under 15 years were placed into the unknown category)

Age Method Results:

When the age ranges used by Ríos and Cardoso were applied to rib fusion in the Town Creek sample, their estimates produced a low (57%) accuracy. Accuracy was determined by the percent of estimated ages that were correctly predicted by the Ríos and Cardoso method. If the age estimates provided by the NAGPRA Inventory Catalog (Davis et al 1998) fell within the ranges provided by Ríos and Cardoso (2009) for each rib, then the individual was correctly predicted by the Ríos and Cardoso age estimation method. When only the head fusion was used to estimate age, the accuracy improved to 64%, which is consistent with the results from Amarna and the Terry Collection.

Table 16 – Age Ranges for Female Head Fusion at Town Creek

Rib Number	Stage1	Stage2	Stage3
1	—	14-15 (n=3)	16-27 (n=16)
2	—	14-15 (n=3)	16-27 (n=16)
3	—	14-15 (n=2)	16-27 (n=16)
4	—	14-15 n=2)	16-27 (n=16)
5	—	14-15 (n=2)	16-27 (n=16)
6	—	14-15 (n=2)	16-27 (n=16)
7	—	14-15 (n=2)	16-27 (n=16)
8	—	14-15 (n=2)	16-27 (n=16)
9	—	14-15 (n=3)	16-27 (n=16)
10	—	14-15 (n=2)	16-27 (n=16)
11	—	—	16-27 (n=16)
12	—	—	16-27 (n=16)

Table 17 - Age Ranges for Male Head Fusion at Town Creek

Rib Number	Stage1	Stage2	Stage3
1	—	—	19-26 (n=6)
2	—	—	19-26 (n=7)
3	—	—	19-26 (n=5)
4	—	—	19-26 (n=5)
5	—	—	19-26 (n=6)
6	—	—	19-26 (n=6)
7	—	—	26 (n=2)
8	—	—	25-26 (n=4)
9	—	—	19-26 (n=5)
10	—	—	26 (n=2)
11	—	19 (n=2)	19-26 (n=4)
12	—	—	25-26 (n=3)

Table 18 - Age Ranges for Individuals Without Sex Estimation Head Fusion at Town Creek

Rib Number	Stage1	Stage2	Stage3
1	10-12 (n=3)	—	—
2	10-12 (n=5)	11 (n=1)	20-21 (n=3)
3	10-12 (n=3)	11 (n=1)	20-21 (n=2)
4	10-12 (n=3)	11 (n=1)	20 (n=1)
5	10-12 (n=3)	11 (n=1)	20 (n=1)
6	10-12 (n=3)	11 (n=1)	20 (n=1)
7	10-12 (n=3)	11 (n=1)	20 (n=1)
8	10-12 (n=3)	11 (n=1)	20 (n=1)
9	10-12 (n=5)	11 (n=2)	20 (n=1)
10	12 (n=1)	—	—
11	12 (n=1)	—	—
12	11(n=1)	—	—

Sex Differences:

A chi square analysis of differentiation by sex was also performed on the Town Creek sample, and the results for some of the ribs are below. In contrast to Amarna, none of the ribs as

Town Creek demonstrate sex differentiation in fusion versus non-fusion. It is possible that the results are affected by the small sample size.

Table 19 – Chi square and p values for selected ribs

Rib Number	1	2	3	4	5	10	11
χ^2	1.303	1.412	1.105	1.481	1.538	1.397	0.00
P	0.254	0.235	0.293	0.224	0.215	0.237	1.00

Conclusions:

Similar to the Terry Collection and Amarna, the Town Creek sample showed narrower age ranges when only the head fusion was observed. The accuracy of the method increased when only the head epiphyses were observed. The chi square analysis indicates that there was not sexual differentiation between male and female maturation of the rib epiphyses, which contrasts with the Amarna sample starkly. One possible explanation for the discrepancy is that the Town Creek sample size is very small, and there are more females than males.

Chapter 4

GROWTH AND DEVELOPMENT

Growth and development in the human body is the result of the complex interaction between our genes and the environment. The idea that environmental stress, whether nutritional or otherwise, impacts growth and development is by no means new. In 1952, Palsson and Verges published the result of an experiment where two populations of lambs of balanced sexes were reared on widely different (High and Low) planes of nutrition. The effect of early nutrition on the growth and relative development of the body proportions was studied by the authors. As regards the skeleton, individual bones or skeletal parts were retarded in development in direct relation to their growth intensity at each age interval. At birth the earliest maturing bones were relatively less developed than the other bones in the low-plane lambs, while at later ages the development of the late maturing bones was proportionately much more affected. Not only did the plane of nutrition affect the weight of the individual skeletal elements, but it also affected the form of the bones in a comparable way. The late developing growth in thickness was retarded by poor nutrition to a much greater extent than the earlier developing length growth in postnatal life (Palsson and Verges 1952).

Nutrition and infection are the two most important driving forces behind environmental stress on growth. Poor nutritional status can lead to impaired immunocompetence and reduced resistance to infection. Additionally, exposure to infectious disease can lead to a combination of anorexia, malabsorption, as well as elevated basal metabolic rate due to fever and protein catabolism (King and Ulijaszek 1999). This relationship between infection and malnutrition is synergistic. Poorly nourished individuals are more susceptible to infection, and infection worsens nutritional status (Ulijaszek and Strickland 1993). Individuals with relatively poor diets suffer proportionally more from the effects of infection.

In order to understand the mechanism that leads to the interaction between nutrition and infection, it is crucial to view malnutrition through a life history framework. The basic principal behind life history theory is that the amount of energy available to an organism is finite, and that energy is allocated to certain crucial functions, and once that investment is made, the energy cannot be devoted to other functions. In other words, trade-offs are the result of an evolutionary compromise between energy costs and time. The host body needs to allocate

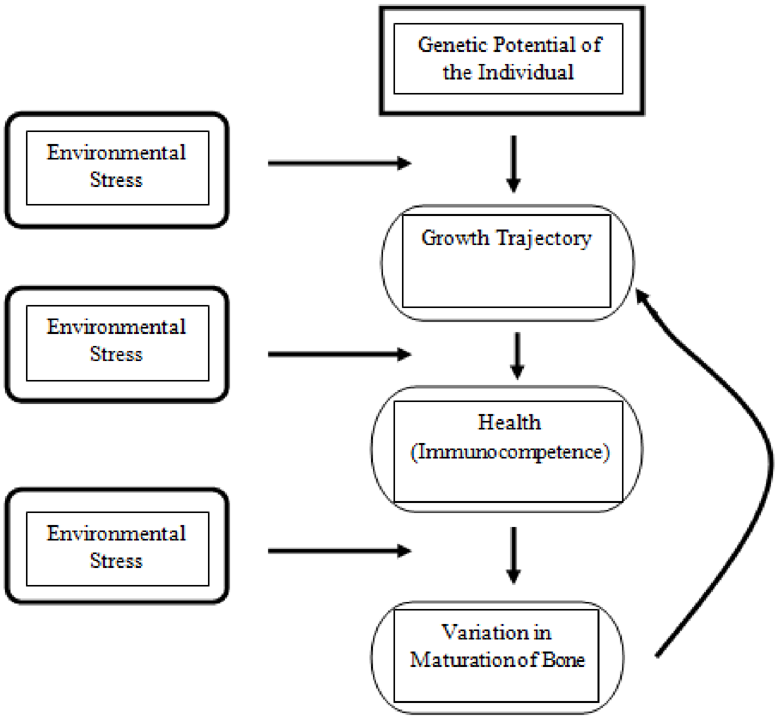

Figure 15 - Model of environmental stress impact on growth and development

energy resources to growth and the immune system. However, when there are limited energy reserves, systems with more priority, like the immune system, will be supported before other systems.

In populations that support high infectious disease loads and have limited energy reserves, host bodies are forced to support immune function over other crucial systems. This process is magnified in younger individuals because they are in the processes of growing rapidly (McDade 2008). A tradeoff therefore occurs between growth and adequate immune system function. A general trend in malnourished populations is that shorter children have a higher morbidity and mortality (McDade 2008). McDade (2010) describes how exposure to nutritional stress in early life can lead to inflammation, which is a response of the innate immune system. He argues for the hygiene hypothesis, and describes that children exposed to microbes in their first few years of life have lower level of C-reactive protein (CRP), which is an indicator of inflammation (McDade 2010).

Disease response can vary from one individual to another for a variety of reasons, including host health and immune status. Host health is influenced by a variety of factors including nutritional status, exposure to disease, and infection. Tang et al. (2007) discusses how malnutrition depresses immune function as well (Tang et al. 2007). Furthermore, there are many environmental factors that can influence disease response as well. Often, sources of contaminated water can lead to repeated exposure to bacteria (for example Shigella) has been shown to weaken children, forcing them to use their energy reserves towards the immune system and stunting growth (McDade 2010).

This well known tradeoff between growth and immune function provides an excellent measure of population health, especially among children and adolescents. In a study of the rate of growth in height and the timing of adolescent growth events for two samples of Guatemalan children, Bogin and Mcvean (1992) documented significant differences between children of differing SES. They found that some compensation for reduced growth during childhood may occur during adolescence by altering either the time of onset, intensity, or duration of the growth spurt (Bogin and Mcvean 1992). The mixed longitudinal analysis of Mayan (low SES) and *ladino* (high SES) growth indicated that Mayan boys had a significantly later age for the onset of the adolescent growth spurt compared with *ladino* boys from well-to-do families. Mayan girls, in contrast, did not appear to differ from *ladina* girls in the timing of the onset or peak velocity of the adolescent spurt. It is clear that in comparison with the high SES *ladinos* the low SES Mayans experience a reduction in the amount of growth and in the velocity of growth at many ages. Mayan boys, and to a lesser extent Mayan girls, also show delays in the timing of developmental milestones, such as age at the onset of puberty and peak height velocity (Bogin and Mcvean 1992).

However, there are certainly challenges to using height as a measure of growth and therefore health in adolescents. On the one hand, shorter stature, especially among younger adolescents, may be a result of delayed maturation associated with under nutrition in childhood. Studies in western populations have shown that the differences in growth status over time are greatest during the adolescent years (Zemel and Jenkins 1989). The timing of the adolescent growth spurt is the major source of the differences between high SES populations and low SES populations. A similar pattern emerges with the Bundi, where urban-rural differences and long-term changes in the rural sample can be, in large part, attributed to an earlier growth spurt (Zemel and Jenkins 1989). However, the rate of growth is readily influenced by current nutrition and the timing of the adolescent growth spurt may be a more sensitive indicator of nutritional status over childhood. As humans adapt to nutritional stress, the tempo of growth and not adult size is the more flexible feature in human plasticity.

Recent work in human populations has further supported that environmental stress such as poor nutrition or disease has a significant impact on skeletal maturation. In their work with large living samples, Schmeling et al. (2000, 2006) and Meijerman et al. (2007) have found that the socioeconomic status (SES) of the samples has a significant impact on age estimation from the state of maturation of the wrist and clavicle (Schmeling et al. 2000; Schmeling et al. 2006; Meijerman et al. 2007). According to Frisancho, a delay of about 1 year in bone age can be expected in low socioeconomic status individuals Frisancho, Garn, and Ascoli 1970).

Chapter 5

A COMPARISON OF THE ARCHAEOLOGICAL AND MODERN SAMPLES

Methods

First, summary tables were created for ribs 2 and 5 that show the total number of ribs per side (left or right). Second, the age at death versus stage of fusion data was analyzed in order to visualize the differences between fusion for the modern and archaeological samples. Using Systat, a scatter plot with linear regression of age at death versus stage of fusion and a box plot of age at death versus stage of fusion were made in order to explore the data. Finally, several statistical methods including a Wilcoxon non-parametric test, a sign test, and a Kolmogorov-Smirnov test, were used to determine the presence of fluctuating bilateral asymmetry.

Results

The summary tables, which present the summary of the rib counts for ribs of each side, (Appendix A) confirm that stage 3 is the most represented stage for the three samples. The scatter plot (Figure 16) clearly demonstrates the three different trajectories of fusion for the different samples. Fusion at Amarna seems to be occurring later than fusion for the other two samples. It is unclear from this figure how fusion at Town Creek compares to the Terry Collection. However, in the box plots (Figure 17), stage three (the best represented stage) Town Creek appears to be fusing later, and over a longer range of age.

The scatter and box plots confirm that the Ríos and Cardoso (2009) age estimation method does not have enough elasticity to accommodate these archaeological samples. However, using their method, a population specific age estimation can be created using epiphyseal union of the vertebral rib ends. In the introduction to this thesis, two hypotheses that provide an explanation for the differences in the age at fusion were briefly discussed.

The differences in the ages of fusion between the two populations are best shown in the following graphs on data from rib 2.

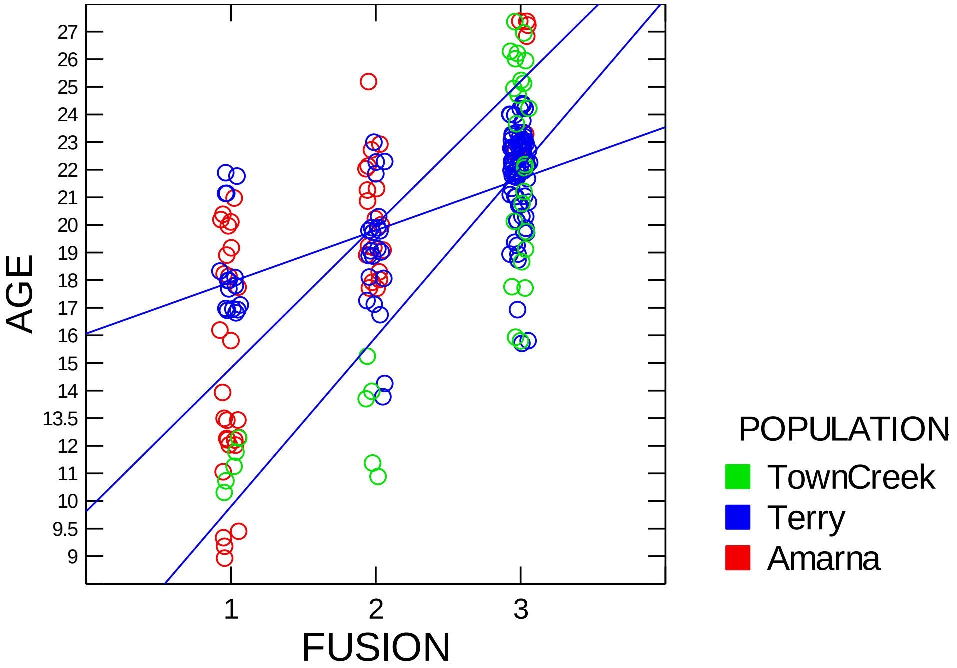

Figure 16 – Scatter plot of age at death versus stage of fusion for the three samples for the 2nd ribs

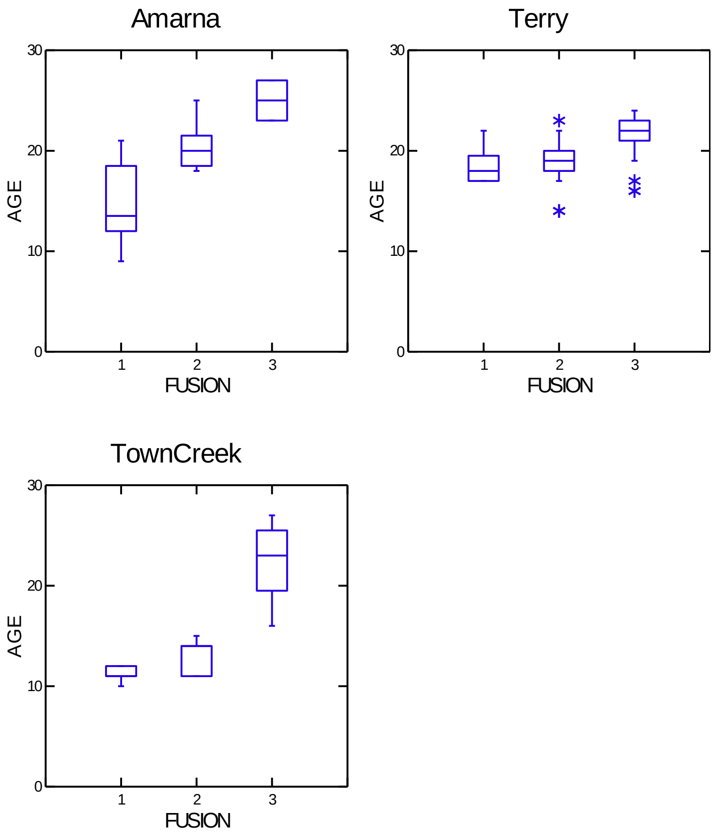

Figure 17 – Box plots showing average and outliers of age at death versus fusion for the three samples for the 2nd ribs

The method used for assessing the presence of fluctuating bilateral asymmetry is described in the Ríos and Cardoso 2009 article (Ríos and Cardoso 2009). In order to assess asymmetry, two questions must be answered: is there asymmetry, and if so, is there directionality. As described in the Ríos and Cardoso article, for each epiphysis, three variables were created. One variable was created for right-side epiphyseal union (ASR), another for left-side epiphyseal union (ASL), and the third was a total score of asymmetry (AST). These variables are defined as the sum of the epiphyseal stages' scores of the three centers of secondary ossification. For example, the sum of the fusion scores for the head of each right rib represented the ASR for head fusion.

Two different statistical tests were applied to the ASR and ASL variables to determine the presence of a significant directional asymmetry. The Wilcoxon non-parametric test, which is used when comparing two related samples or repeated measurements on a single sample to assess whether their population means differ, was used to determine the presence of a significant difference between ASR and ASL (Siegel 1956). Then, sign tests were also used to assess whether the asymmetry was directional. Then, the distribution of AST values was compared with the Poisson distribution to assess whether asymmetric cases were just rare events in comparison with symmetric cases (AST = 0). The Kolmogorov-Smirnov test was used to assess the fit (Rios and Cardoso 2009). The Kolmogorov–Smirnov statistic quantifies a distance between the empirical distribution function of the sample and the cumulative distribution function of the reference distribution. The null distribution of this statistic is calculated under the null hypothesis that he sample is drawn from the reference distribution (Poisson distribution) (Corder and Foreman 2009).

The analysis of fluctuating bilateral asymmetry showed that while the Amarna and Town Creek populations experienced non-directional asymmetry, the Terry collection did not. The Terry Collection results are very similar to the data of Ríos and Cardoso. The Wilcoxon test did not show any significant difference between ASR and ASL for the three epiphyses (head, P= 0.407; articular tubercle, P=0.402; non-articular tubercle, P=0.389). In contrast, the Wilcoxon test for Amarna and Town Creek showed a significant difference at all three tubercles. At Amarna head fusion was less significantly different than the other two tubercles (head, P=0.0489; articular tubercle, P=0.0212; non-articular tubercle, P= 0.0233). The same pattern existed for the Town Creek sample (head, P=0.0474; articular tubercle, P=0.0314; non-articular tubercle, P= 0.0253). The fact that head fusion is less significantly different may explain why using the head epiphysis to estimate age appears to be more accurate. All of the sign tests for the three populations were statistically insignificant, which indicates that the asymmetry is not directional. Additionally, none of the samples fit a Poisson distribution, suggesting that bilateral asymmetry was not a random event in any of the populations. Overall, the Amarna and Town Creek individuals showed more asymmetry (Amarna, 84%; Town Creek, 60%). On the Terry Collection, by far the largest sample, only 42% of the individuals showed bilateral asymmetry.

Conclusions

The first hypothesis stated that environmental stress caused an interruption in the maturation of the individuals at Amarna and Town Creek, thus causing the delay in the age of fusion observed in these two samples. In order to assess the potential validity of this hypothesis, bilateral asymmetry was recorded in each of the samples. Previous findings regarding the possible importance of asymmetry in the degree of fusion in bilateral epiphyses, as indicative of environmental stress indicate that the presence of fluctuating asymmetry at Amarna and Town Creek could provide an explanation for the difference in fusion (Albert and Greene 1999). The Albert and Greene study (1999) examined the efficacy of bilateral asymmetry in epiphyseal union as an indicator of environmental stress in the skeleton. They compared the extent of asymmetry in the postcranial skeleton between two cemetery samples excavated from Medieval Kulubnarti, Sudanese Nubia. According to the authors, past studies have strongly suggested that these ancient Nubians experienced environmental stress - the early Christian period (550–750 AD) population to a greater extent than the late Christian period (750–1450

AD) population. They hypothesized that if bilateral asymmetry is a reflection of stress, then it should be present or greater in the more stressed population, the early Christian period population, while absent or found to a lesser extent in the less stressed population, the late Christian period population. They computed two mean values, representative of right-side and left-side epiphyseal union, for each individual in both cemetery samples, and tested for significant differences. When cemetery samples were tested separately, bilateral asymmetry was significant for the early Christian period sample ($P < 0.001$), but not for the late Christian period sample, thus indicating that asymmetry was an indicator of environmental stress (Albert and Greene 1999). Evidence was found for the presence of bilateral asymmetry in the two archaeological samples. Bilateral asymmetry between the left and right ribs occurs when the fusion of the epiphyses of ribs on one side occurs at a different age than ribs on the other side. As opposed to uniform and predictable fusion, an individual with bilateral asymmetry and a delay in fusion shows a disruption in the development and growth of the epiphyses. While genetics undoubtedly plays an important role in determining when these rib epiphyses fuse, it is much more likely that environmental stress is inhibiting fusion of certain ribs, thus creating the pattern of bilateral asymmetry. However, evidence linking bilateral asymmetry to environmental stress is limited. Therefore, I cannot rule out that sample bias caused the discrepancies between the two archaeological samples and the modern sample.

The second hypothesis states that sample bias caused the differences in the population. While this hypothesis cannot be disregarded or disproven, there is some evidence against sample bias causing the difference in age at fusion. When the Terry Collection sample was first tested using the Ríos and Cardoso (2009) method, only 27 individuals were observed. On a second trip, the remaining 33 individuals were observed. There was no difference in the average ages at the three stages of fusion after the sample more than doubled. In addition, the difference in age at fusion which was first seen at Amarna, was also seen in another archaeological sample (Town Creek) which was completely geographically distinct from the Amarna sample.

Some of the strongest evidence supporting the first hypothesis is the difference in femur lengths of people born at Amarna, and people who grew up before that time (Chapter 1). Not only are younger people at Amarna shorter, but they are also dying at a higher rate than older individuals. Those people who survived beyond adolescence lived for a long time - many suffered from extensive chronic disease (ex. Arthritis) (Valdes 2010). At Amarna, there is a high rate of the co-occurrence of diseases related to nutritional deficiency in the commoner's cemetery. Of the 36 individuals observed at Amarna, 79% showed either porotic hyperostosis, cribra orbitalia, or more than 2 enamel hypoplasias (Valdes 2010). The co-occurrence of metabolic disorders, the high incidence of adolescent deaths (Amarna), and the presence of bilateral asymmetry at the two archaeological sites strongly suggests that environmental stress caused the delay in the fusion of the epiphyses of the vertebral rib ends.

The utility of the Ríos and Cardoso method on modern populations is limited by the broad ranges of age estimates produced when using all three epiphyses. However, this method becomes much more accurate and practical when only the head epiphysis is used to estimate age. The chi square analysis of sex differences in fusion for all three samples indicates that sexual maturation may have significant effect on the timing of fusion. Therefore, sex estimates are crucial to the successful implementation of this method on any population. The Ríos and Cardoso method has several limitations when used to estimate age for individuals from archaeological samples. First, the ranges of age estimation provided by the method are much broader than other methods (dental, long bone fusion), except when using only the head epiphysis. Second, in both the archaeological samples tested in this thesis, the age estimates provided by Ríos and Cardoso for the particular stages of fusion at each rib did not accurately capture the age estimates provided by dental methods. Third, population specific ranges of age estimation are necessary to use this method on archaeological samples, which is a time consuming process. However, despite the limitations to the utilization of the Ríos and Cardoso method on archaeological populations, this method can be useful for samples where some of the individuals lack dental age estimates. In order to expedite the use of this method, the second and ninth ribs are well represented in the archaeological record (because of their robusticity), and assessing fusion is easiest for these ribs.

WORKS CITED

Albert AM, Greene DL. 1999. Bilateral asymmetry in skeletal growth and maturation as an indicator of environmental stress. *American Journal of Physical Anthropology* 110:341–349.

Bass, W. M. 1995. *Human Osteology: A Laboratory anf Field Manual.* 4th Edition. Columbia, Missouri: Missouri Archaeological Society.

Bogin, B., Wall, M. and Macvean, R. B. 1992. Longitudinal analysis of adolescent growth of *ladino* and Mayan school children in Guatemala: Effects of environment and sex. *American Journal of Physical Anthropology* 89: 447–457.

Buikstra, J., and D. Ubelaker. 1994. *Standards for Data Collection from Human Skeletal Remains.* Fayetteville, AR.

Cardoso, Hugo F.V. 2008b. Age Estimation of Adolescent snd Young Adult Male and Female Skeletons II. *American Journal of Physical Anthropology* 134: 97-105.

Coe et al. 1995. *Town Creek Indian Mound: A Native American Legacy.* The University of North Carolina Press.

Corder, G.W., Foreman, D.I. 2009. *Nonparametric Statistics for Non-Statisticians: A Step-by-Step Approach* Wiley.

Davis, R.P. Steven, Patricia M Lambert, Vincas P Steponaitis, Clark Spencer Larsen, and Trawick H Ward. 1998. *An Abbreviated NAGPRA Inventory of the North Carolina Archaeological Collection.* Research Laboratories of Archaeology, The University of North Carolina at Chapel Hill.

Frisancho AR, Garn SM, Ascoli W. 1970a. Unequal influence of low dietary intakes on skeletal maturation during childhood and adolescence. *Am J Clin Nutr* 23:1220–1227.

Hunt, David R. "Terry Collection." *NMNH Anthropology.* http://anthropology.si.edu/cm/terry.htm (accessed April 2010).

İsçan, MY, and SR Loth. 1984. Age Estimation from the Rib PhaseAnalysis: White Males. *Journal of Forensic Science* 29: 1094-1104.

Kemp B. 1994. Feeding an Egyptian city in Rowley-Conwy P., Luff R. (eds.) *Whither Environmental Archaeology* Oxford, 141.

Kemp B. 2006. *Ancient Egypt: Anatomy of a Civilization*. London, 328-329.

King SE, Ulijaszek SJ. 1999. Invisible insults during growth and development: contemporary theories and past populations. In: Hoppa RD, FitzGerald CM, editors. *Human growth in the past: studies from bones and teeth*. Cambridge: Cambridge University Press 161–182.

Marieb, Elaine N., and Katja Hoehn. 2008. *Anatomy and Physiology.* San Francisco: Pearson Education 3.

Meijerman L, Maat GJR, Schulz R, Schmeling A. 2007. Variables affecting the probability of complete fusion of the medial clavicular epiphysis. *Int J Leg Med* 121:463–468.

McDade T. W.2005. Life history, maintenance, and the early origins of immune function. *Am. J. Hum. Biol.* 17: 81–94.

McDade TW, Reyes-Garcia V, Blackinton P, Tanner S, Huanca T, Leonard WR. 2007. Ethnobotanical knowledge is associated with indices of child health in the Bolivian Amazon. *PNAS* 104:6134–6139.

McDade, TW, Reyes-García, V., Tanner, S., Huanca, T. and Leonard, WR. 2008. Maintenance versus growth: Investigating the costs of immune activation among children in lowland Bolivia. *American Journal of Physical Anthropology* 136: 478–484.

McDade, TW. 2010. Early origins of inflammation: microbial exposures in infancy predict lower levels of C-reactive protein in adulthood. *Proceedings Of The Royal Society B-Biological Ssciences. 277:* 1129-1137.

McKern, TW, and TD Stewart. 1957. Skeletal Changes in Young American Males. Analyzed from the standpoint of age identification. *Evironmental Protection Research Division Technical Report* (U.S. Army Quartermaster Research and Development Command) 45.

Murnane W. *Texts from the Amarna Period in Egypt*. Atlanta, 1995, 75.

Ortner, Donald J. 2003. *Indentification of Pathological Conditions in Human Skeletal Remains.* 2. Academic Press.

Palsson, H. and J.B. Verges. 1952. Effects of the plane of nutrition on growth and development of carcass quality in lambs. Part I. The effects of high and low planes of nutrition at different ages. *J. Agric. Sci.* 42: 1–92.

Rios, Luis, and Hugo F.V. Cardoso. 2009. Age Estimation From Stages of Union of the Vertebral Epiphyses of the Ribs. *American Journal of Physical Anthropology* 140: 265-274.

Rose, Jerome C, Barry Kemp, and Melissa Zabecki. 2008. Presumed Opulence and Actual Deprivation at Tell el-Amarna.

Scheuer, Louise, and Sue M. Black. 2004. *Developmental Juvenile Osteology.* San Diego: Elsevier Academic Press.

Schmeling A, Reisinger W, Loreck D, Vendura K, Markus W, Geserick G. 2000. Effects of ethnicity on skeletal maturation: consequences for forensic age estimations. *Int J Legal Med* 113:253–258.

Schmeling A, Schulz R, Danner B, Rosing FW. 2006. The impact of economic progress and modernization in medicine on the ossification of hand and wrist. *Int J Legal Med* 120:121–126.

Siegel, Sidney. 1956. *Non-parametric statistics for the behavioral sciences.* New York: McGraw-Hill 75–83.

Tang A, Smit E, Semba R. 2007. Chapter 12: Nutrition and Infection. *Infectious disease epidemiology: theory and practice.* In: Nelson K, Willaims C, editors. Jones & Bartlett Learning 383-406.

Ulijaszek SJ, Strickland SS. 1993. *Nutritional anthropology:prospects and perspectives.* London: Smith-Gordon.

Valdes, Ashley. 2010. Co-occurrence of Metabolic Disorders at Amarna. *Amarna Project.*

White, Tim D. 2000. *Human Osteology.* San Diego: Academic Press.

Zemel, B. and Jenkins, C. 1989. Dietary change and adolescent growth among the Bundi (Gende-speaking) people of Papua New Guinea. American Journal of Human Biology 1: 709–718.

APPENDIX A

Table 20 – Summary Table of Left Second Rib Distribution at the Terry Collection

Age	Stage 1	Stage 2	Stage 3	Total
14	0	1	0	1
16	0	0	1	1
17	3	1	1	5
18	3	1	0	4
19	0	2	3	5
20	0	3	4	7
21	1	0	4	5
22	1	2	11	14
23	0	0	12	12
24	0	0	4	4
Total	8	10	40	58

Table 21 - Summary Table of Left Second Rib Distribution for the Amarna Sample

Age	Stage 1	Stage 2	Stage 3	Total
9	1	0	0	1
9.5	0	0	1	1
12	3	0	0	3
13.5	1	0	0	1
16	1	0	0	1
18	2	2	0	4
19	1	2	0	3
20	2	1	0	3
21	1	1	0	2
22	0	0	4	4
23	0	1	2	3
25	0	1	0	1
27	0	0	2	2
Total	13	9	4	26

Table 22 - Summary Table of Left Second Rib Distribution for the Town Creek Sample

Age	Stage 1	Stage 2	Stage 3	Total
11	1	1	0	2
12	1	0	0	1
14	0	1	0	1
16	0	0	1	1
18	0	0	1	1
19	0	0	1	1
20	0	0	1	1
21	0	0	1	1
22	0	0	1	1
24	0	0	0	1
25	0	0	2	2
26	0	0	2	2
27	0	0	1	1
Total	2	2	12	16

Table 23 - Summary Table of Right Second Rib Distribution at the Terry Collection

Age	Stage 1	Stage 2	Stage 3	Total
14	0	1	0	1
16	0	0	1	1
17	3	2	0	5
18	3	1	0	4
19	0	3	2	5
20	0	3	3	6
21	1	0	4	5
22	1	1	10	12
23	0	1	11	12
24	0	0	4	4
Total	8	12	35	55

Table 24 - Summary Table of Right Second Rib Distribution for the Amarna Sample

Age	Stage 1	Stage 2	Stage 3	Total
9	1	0	0	1
9.5	1	0	0	1
11	1	0	0	1
12	3	0	0	3
13.5	2	0	0	2
14	1	0	0	1
16	1	0	0	1
18	1	3	0	4
19	1	2	0	3
20	2	1	0	3
21	0	2	0	2
22	0	1	0	1
23	0	1	2	3
27	0	0	2	2
Total	14	10	4	28

Table 25 - Summary Table of Right Second Rib Distribution for the Town Creek Sample

Age	Stage 1	Stage 2	Stage 3	Total
10	1	0	0	1
11	1	1	0	2
12	1	0	0	1
14	0	1	0	1
15	0	1	0	1
16	0	0	1	1
18	0	0	1	1
19	0	0	1	1
20	0	0	1	1
21	0	0	1	1
22	0	0	1	1
24	0	0	1	1
25	0	0	2	2
26	0	0	2	2
27	0	0	1	1
Total	3	3	12	18

Table 26 - Summary Table of Left Fifth Rib Distribution at the Terry Collection

Age	Stage 1	Stage 2	Stage 3	Total
14	1	0	0	1
16	0	0	1	1
17	3	0	1	4
18	3	1	0	4
19	0	3	3	6
20	1	2	4	7
21	1	0	3	4
22	1	2	10	13
23	0	1	9	10
24	0	0	5	5
Total	10	9	36	55

Table 27 - Summary Table of Left Fifth Rib Distribution for the Amarna Sample

Age	Stage 1	Stage 2	Stage 3	Total
9.5	1	0	0	1
12	2	0	0	2
13.5	2	0	0	2
14	2	0	0	2
16	2	0	0	2
18	3	1	0	4
19	2	1	0	3
20	3	0	0	3
21	0	1	0	1
22	0	1	0	1
23	0	1	2	3
27	0	0	2	2
Total	17	5	5	27

Table 28 - Summary Table of Left Fifth Rib Distribution for the Town Creek Sample

Age	Stage 1	Stage 2	Stage 3	Total
10	1	0	0	1
11	0	1	0	1
12	1	0	0	1
14	0	1	0	1
19	0	0	1	1
20	0	0	1	1
24	0	0	1	1
25	0	0	1	1
26	0	0	2	2
27	0	0	1	1
Total	2	2	7	11

Table 29 - Summary Table of Right Fifth Rib Distribution at the Terry Collection

Age	Stage 1	Stage 2	Stage 3	Total
14	1	0	0	1
16	0	0	1	1
17	3	1	1	5
18	3	1	0	4
19	1	1	3	5
20	1	3	3	7
21	1	0	4	5
22	1	2	10	13
23	0	1	10	11
24	0	0	4	4
Total	11	9	36	56

Table 30 - Summary Table of Right Fifth Rib Distribution for the Amarna Sample

Age	Stage 1	Stage 2	Stage 3	Total
9.5	1	0	0	1
11	1	0	0	1
12	1	0	0	1
13.5	1	0	0	1
16	2	0	0	2
18	3	2	0	5
19	3	1	0	4
20	1	2	0	3
21	0	1	0	1
22	0	1	0	1
23	0	1	1	2
27	0	1	1	2
Total	13	9	2	24

Table 31 - Summary Table of Right Fifth Rib Distribution for the Town Creek Sample

Age	Stage 1	Stage 2	Stage 3	Total
11	0	1	0	1
12	1	0	0	1
14	0	1	0	1
24	0	0	1	1
25	0	0	2	2
26	0	0	2	2
Total	1	2	5	8