Identification of Paleopathological Conditions in a Non-Adult Population from Roman Age Sirmium, Serbia: A Bioarchaeological and Life History Approach

by

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Abstract

Identification of Paleopathological Conditions in a Non-Adult Population from Roman Age Sirmium, Serbia: A Bioarchaeological and Life History Approach

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The purpose of this dissertation is to assess the status of child health within the context of Late Roman Sirmium, Serbia (ca. 1^{st} – 6^{th} Century CE) through the evaluation of multiple indicators of skeletal stress (porotic hyperostosis, enamel hyperplasia, and infectious disease). Children and other non-adults (infants and adolescents), for a number of reasons, have been "*marginalized*" within the fields of archaeology and bioarchaeology. Differential preservation, burial bias, incorrect identification children and non-adult bones and culturally focused definitions of children are among some of the reasons often cited for the lack of research specifically targeting these populations.

This dissertation attempts to address this issue of marginalization and that of child morbidity and mortality during the Late Roman Period, recognizing that children and other non-adult cohorts represent important segments of archaeological skeletal populations that can add significant information on past human behavior.

The research employed by this thesis will take a holistic bioarchaeological approach by incorporating data from a variety of fields and methodologies, including archaeology, historical records, and environmental science. The primary data, however, will come directly from the analysis of non-adult skeletal material recovered from the Late Roman Period Cemetery, St. Sineros on the northeast border of Sirmium. This dissertation will use both qualitative, looking at the life histories of individuals, and quantitative data to reconstruct patterns of health and disease, in addition to Roman cultural practices (i.e. breastfeeding) that often dictated behaviors that directly influence the non-adult the late Roman Period in Sirmium.

Key Words: Bioarchaeology; Paleopathology; Serbia; Sirmium; Pannonia; Roman; Non-Adults

Dedication

To my family and loved ones.

Acknowledgements

I would like to begin by thanking my dissertation committee, Dr. Thomas McGovern, Dr. Arthur Bankoff and Dr. Haviva Goldman with special thanks to Dr. Sophia Perdikaris for guiding me through this dissertation. I would also like to thank Dr. Bonnie Gustav and Dr. Edward L. Ochsenschlager for their help with the initial collection of material. To my colleagues at Brooklyn and Hunter College, Cory, Konrad, Norie, Reaksha and Erin and everyone else, thanks for your support. Most importantly I would like to thank my family and Diana for supporting me through this process.

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Chapter 1

Introduction

1.1 Introduction

Scholarly writings pertaining to the history and archaeology of the Roman Empire have rarely looked at human remains as vital segments of the archaeological record (but see Morris 1992). Focus directed at architecture, pottery, military, politics, formation of towns, and rise and fall of the Empire have all shared the central focus of Classical Roman archaeology and history. Numerous volumes of literature written on the Roman Empire over the last one and one half centuries have rarely if at all mentioned human skeletal analysis in any real substantial amount. While the abovementioned topics are essential the richness of picture and interpretation of Roman archaeology is incomplete without incorporating bioarchaeological data. While there has been some change in recent years more work is still needed in specific areas and time periods of the Roman Empire.

The bioarchaeology of Roman Pannonia is underdeveloped in comparison with the quantity of research that has been conducted on skeletal material from other areas of the Roman World. Much of the information about this particular region and time period, as it relates to human skeletal remains, is often found as parts of chapters of larger works and little time and space is afforded this important province. Two volumes written in the 70's (Mócsy, 1974) and early 80's (Lengyel and Radan, 1980) specifically pertain to the Roman occupation of Pannonia. Both of these works include information on the general history taking a chronological approach as well as including evidence obtained from archaeological excavations. These works are lacking. There is no information that considers human skeletal material, except for a brief appendix by Lengyel

(1980). There is no link between periods of disease, famine, or economic or social stress with actual skeletons which as Morris (1992) has put forth would '…augment the written record, giving us for the first time a dynamic account of social structure…'

During the late 1960's and early 1970's archaeological investigations were carried out at Sirmium in Pannonia under a joint research project between the City University of New York and the Archaeological Institute of Belgrade funded primarily by the Smithsonian Institute. Over a period of 6 years a number of locations within Sirmium and surrounding area were excavated. Primary goals were related to formation of the Roman town and to a lesser extent the skeletal remains. However, no in depth publications or reports were completed on any of the skeletal material that was excavated during these excavations.

Milosevic (1971) published a short paper on the history of archaeological work in Sirmium. In this paper excavations of at least 2 cemeteries are discussed. Much of the focus of earlier excavations in Sirmium, specifically related to cemeteries was directed at tomb structures and or identifying the relationship between specific structures and specific saints that were believed to have been martyred in Sirmium (Milosevic 1971). More importantly, the skeletal material excavated during the 1969 and 1970 season was not included. There is no question that Sirmium during its period as a city within the Roman Empire had a rich history as has been identified archaeologically and historically, however, it still lacks vital bioarchaeological data. The skeletal material used for this research will add crucial and fundamental information regarding culture and biology of those that lived in Sirmium between the 1st and 6th century AD.

Approximately 285 individual skeletal remains were excavated between 1969 and 1970 from a multi-period Roman cemetery from the city of Sirmium in Serbia. This study targets the non-adult population ages -fetal to adolescent (0-17 years of age) - from the Sirmium collection. The research presented here attempts to identify patterns of health and disease of non-adults focusing on diseases of nutrition, infection, and dental disease, as well as the effects of these maladies on growth. They will be viewed in relationship to culture practices (breast feeding), environment, society (age and class structure) and major events (warfare, famine, epidemics), that potentially increased the risk of mortality and morbidity above the normal risk associated with individuals of this age range, between the 1st and 6th century AD.

1.2 Bioarchaeology

The line that separates humans as biological organisms and humans as cultural organisms should be thought as being almost non-existent and it might be best not to visualize a boundary separating human biology and culture and instead view it more as a fluid relationship in which the biological and cultural variables that define us are constantly interacting with each other.

As such making definitive statements about our biological make up without taking into consideration cultural and environmental influences is flawed just as it is to make definitive statements about human culture without taking into consideration the influence from biology and environment. Devernski (2000) notes that the human skeleton represents this specific point of intersection where human biology and human culture meet.

Bioarchaeology has been defined by Larsen (1997) as the study of human skeletal material from archaeological contexts but the foundation of this field and the suggested methodology was detailed approximately 20 years earlier when Buikstra (1979) discussed the importance of contextual information and the collaboration between the physical anthropologist and the archaeologist on research relating to human skeletal material from archaeological sites.

Human skeletal material (bone and dental) retain vital information pertaining to past human behavior. Disease, diet, environment (cultural and natural), and human activity can all be potentially identified through the analysis of human skeletal material. These factors are at the root of human variation and adaptation often acting at the same time at the individual and population level. While the interpretation, understanding and accurate placement of these genetic, morphological and cultural variations are difficult, the theoretical and methodological frame work of bioarchaeology allows for the bridging of archaeological methods and biological and physical anthropological sciences which in turn allows for a biocultural understanding of past human societies.

The theoretical foundation of this research is firmly rooted in bioarchaeology (Larsen 2006, Lewis 2007, Goldstien 2006) and paleopathology (see Ortner 2003) and the link focusing on the intimate and synergistic relationship between environment, culture and human biology. More specifically this work will utilize the foundation set out by Goodman and Armelagos (1989) that identifies stress or "physiological imbalance" as resulting from 3 main factors; environment, cultural systems, and host resistance (Goodman and Armelagos 1989). While environment (lack of essential resources), and individual genetic make-up can and do lead to stress and disease, it is

ultimately culture that dictates who gets what and how much of a specific resource as well as dictating the manner in which humans deal with environmental and biological stress.

This work also takes the approach that non-adults especially children while not reproductive (biologically) members they are an active and integral group with in a specific culture. Furthermore, decisions made regarding allocation of resources not only specifically affect non-adults but have overriding implications at a family, community and population level. Limitations associated with bioarchaeological and paleopathological studies will be assessed as they relate to the specific research.

This dissertation takes a bioarchaeological approach, in methodology and theory, as a foundation to analyze the non-adult segment of the population from the St. Sineros (Locality 26) Roman cemetery in Sirmium. It will attempt, through looking at health and disease and cultural practices (mortuary practices, diet, etc…) to gain a better understanding life and death for non-adults from Roman Sirmium.

1.3 Non-Adults and Bioarhaeology - Defining Age (Biology vs. Culture)

This dissertation specifically targets non-adults (0-17 years of age), a subsample of populations that has, until recently, been marginalized in terms of research focus in both in archaeology and bioarchaeology (Halrow and Tayles 2008; Lewis 2007; Baxter 2008). One of the more significant areas of interest and concern associated with non-adult archaeology and bioarchaeology is that of the identification and distinction between age terminology (Deverenski 2000; Baxter 2008; Lewis 2007; Halcrow and Tayles 2008). Age has important implications for

bioarchaeologocal research as it forms much of the foundation for questions, interpretation and understanding of patterns of morbidity and mortality in past populations. Recent literature, with a specific focus on non-adults indicates that there are three main age types often utilized in bioarchaeology and archaeology; biological/physiological; chronological; and sociocultural (Lewis 2007). .

As defined by Halcrow and Tayles (2008), biological age is based on changes related to growth and development while chronological age is based on time since birth. For bioarchaeologists there is a clear and obvious link between biological and chronological age with age determination calculated based growth changes in the skeleton, which are then converted into a numerical or chronological age. While socio-cultural age shows some relationship to biological and chronological age, it is, however, more difficult to cross culturally define. This particular age type is based on culturally defined behaviors that are specifically related to a given age group or age range within a given time period (Halcrow and Tayles 2008). As such socio-cultural age varies according to the parameters and expectation of a given culture and therefore cannot be used between populations and across time without some risk. To increase the complication associated with this category of age, changes in the behavioral expectations for a specific social age category may change within the same culture over time (i.e. childhood in the 1st century AD Roman Empire might be defined differently during the 2nd century AD). In addition, biological age which is based on physiological changes during growth is directly influenced by cultural behaviors further stressing the point made previously regarding the need to take a biocultural approach for the analysis of human skeletal material from archaeological sites.

Infancy, childhood and adolescence are all culturally defined age divisions that vary according to culture and time period. The use of these age categories for this thesis is based on chronological divisions found in Lewis (2007) and Scheurer and Black (2000). The specific age categories and their associated numerical age ranges can be found in Chapter 3. The behaviors, including diet, marriage and mortuary practices, associated with the sociocultural age groups, as they relate the Roman Period, utilized in this dissertation are found throughout this dissertation.

Chapter 2

History and Archaeology of Roman Sirmium

2.1 History and Archaeology of Roman Sirmium

The primary temporal and spatial focus of this thesis is the Roman city of Sirmium within province of Pannonia between the 1st and 6th century AD. As such this section will give a brief background into the region and city in terms of history, archaeology, geography and environment and will limit comments pertaining to the rest of the Empire. For a more detailed information related to Roman Period Pannonia see Mócsy (1974) and Engyel and Radan (1980).

The history and archaeology of Roman Sirmium begins with the initial conquest of Pannonia by the Romans in the 1st century BC. Figure 2.1 exhibits the geographic boundaries of Pannonia while under the control of the Roman Empire in the early 3rd century AD.

Figure 2.1 – 3rd Century Map of the Roman Empire

Key: Pannonia numbers 4 and 5 map key
Source: University of Texas

Roman Pannonia occupied portions of many modern day Balkan region nations including, Serbia, Bosina-Herzegovina, and Croatia as well as portions of countries that fall outside of the Balkans (Hungary and Austria). Pannonia became part of the Roman Empire in name during the the 2nd half of the first century AD replacing the previous title of Illyricum Inferior. During the Roman Empire, Pannonia was positioned with its northern and part of its eastern border flush against the Danube River while its western boundary was formed by the province of Noricum. To the south and west the provinces of Dalmatia and Moesia, respectively, formed the last of the borders of Pannonia. During the early years of the 2nd century AD, under the rein of Trajan, Pannonia was divided into Pannonia Superior and Pannonia Inferior (see Figure 2.1). By the time this event occurred, Sirmium had already gained its city status which is thought to have occurred in 79AD (Mirković, 1971). Further changes related to the division of Pannonia occurred between during the last decade of the 3rd century AD under the rule of Diocletian when the province was again divided but this time into four regions (Soproni, 1980).

The region of Pannonia encompassed a wide variety of environments, ranging from mountainous regions to lowland swampy areas. In addition, three major river systems, the Danube, Sava and the Drava course their way through or bordered this province. All three played significant roles in protection, travel and trade during the Roman period. While the Pannonian region encompassed large areas of fertile land, for cultivation of crops, including those suited for vineyards and grains, animal husbandry and wild fauna, some of which is known to have been exported to Rome, it is thought to have been lacking in usable minerals (Soproni, 1980). Stone quarries were, however, abundant with raw material being shipped along the major river systems of Pannonia (Duric et al., 2006).

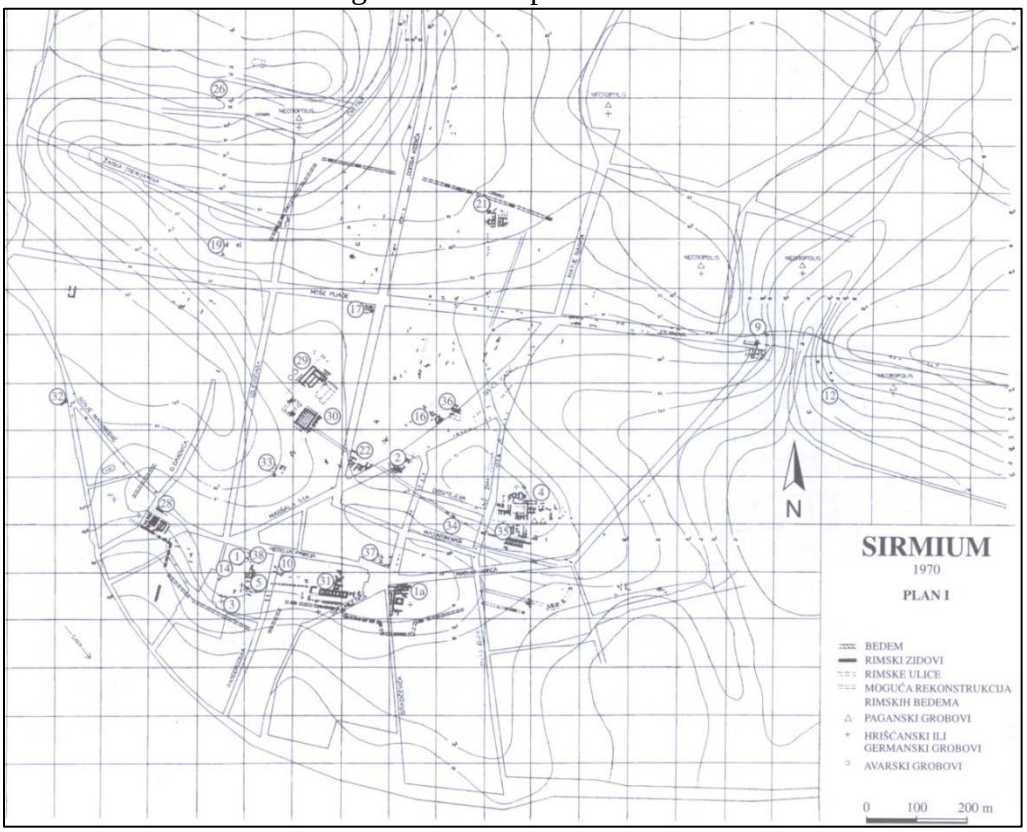
From the initial Roman invasion into the region of Pannonia (1st century BC), an almost constant influx of conflict occurred between the Roman military and the native occupants of this geographic area in addition to the conflict between various groups within Empire. But by the late 1st and early 2nd century, the Roman Empire had a strong foot hold in the region as can be attested to by Pannonia becoming a province of the Empire as well as new growth of new cities and towns. According to Mócsy (1974) it was during this period (1st century) that Pannonia experienced some short periods of peace and prosperity which are incidentally related to the building of towns and the establishment of cities. In addition, trade, which included livestock and slaves, along the road and river systems (Sava and Danube Rivers) increased. These events also coincided with an increase of immigration of Italians into Pannonia (Mócsy 1974) which brought distinctive cultural traits into the region (i.e. ceramics). It was during this period that Sirmium gained city status. These periods of growth and prosperity occurred at different times between the 1st and 6th century AD but were generally overshadowed by an almost constant conflict both within the Roman Empire and from outside sources. These conflicts and their related consequences (famine, disease, etc…) affected different regions of Pannonia with varying severity. As will be discussed below, the full extent of these phenomena on the city of Sirmium and it population is not fully understood.

Roman control over the region ebbed and flowed between the 1st and 6th centuries with various groups other than the Romans claiming ownership to portions of Pannonia. It was not until at least the fall of the Western Empire in the 5th century that Pannonia is lost as a province with some reclamation of part of the region (specifically associated with Sirmium) later in the 6th century AD by the Eastern Empire (Byzantine). The fact that Sirmium, as a city, was still

controlled by Romans late into the 6th century, points to its importance as a city to the Roman Empire in the east.

The archaeological history of Roman Sirmium spans a period of approximately 600 years. From the early 1st century AD until 582 AD Sirmium was an important city of the Roman Empire. The city of Sirmium sits on the east bank of the Sava River approximately 75km northwest of Roman Singindium or modern Belgrade (see Figure 2.1). At its maximum, during the 4th century, Sirmium expanded to approximately 120 hectares (296 acres) or approximately 1 km^2 (see Figure 2.2) and rose to the status of imperial city and provincial capital (Mirkovic, 1971).

Figure 2.2 – Map of Sirmium



General archaeological excavation map of Sirmium
Source: Sirmium Volume 1 (1970)

Currently Sirmium is partially buried beneath the modern city of Sremska Mitrovica, Serbia. Archaeological excavations over the last century have helped to expose some of the rich Roman history of this city. The abundance of information, pertaining to Sirmium is greatly uneven regarding biological, cultural, environmental, social, and archaeological data within specific time frames. Much of the history and to some extent archaeological evidence for Sirmium encompasses the Late Roman period (ca. 3rd-6th century AD) as it relates to military activity, the coming and goings of various emperors, and building projects with much of this information being repeated from similar sources (see Mócsy, 1974; Mirkovic, 1971; Engyel and Radan, 1980).

The Urbanization of Sirmium followed patterns observed throughout the empire and developed during the last quarter of the 1st century and continued to develop in some form into the 3rd century (Póczy, 1980). Some cities were founded in the vacuum left by abandon military settlements while others were founded originally as merchant settlements erected next to a military facilities. More often, however, urbanization took the form of cities and towns built on already inhabited settlements (Wacher, 1987). While there has been some conjecture as to the original formation of Sirmium, it seems most likely, based on archaeological and historical documentation, that Roman Sirmium was constructed on the foundation of an earlier settlement, possibly a commercial trade center (Mirkovic, 1971).

Periods of prosperity and stress affected the growth and development of Sirmium. Excavations conducted during the mid to late 20th century revealed much of the rich archaeological history and permitted for some reconstruction of the structural layout of the city between the 1st and 6th

century. Building projects included the construction of public baths, public granaries, apartment complexes, aqueducts and market places, all of which were identified based on historical records and archaeological excavation. In addition, traces of defensive walls that would have surrounded the city are thought to have been constructed during times of increase conflict as well during times of increased economic prosperity (4th century). To confirm the status of Sirmium as commercial, construction of road systems to the north, east and west were constructed as well as a bridge and piers located on the western and southern edge of the city. These areas were both in close proximity to the market and commercial center of Sirmium. A hippodrome was built in south western area of the city with direct access to the imperial palace, common building practice found in other large Roman cities including Rome. It is thought that during the construction of the hippodrome funds for the projects had to be at least temporally diverted to be used to make repairs on the walls surrounding the city (Póczy 1984), which in part supports the historical writings that talk of constant turmoil affecting the general region, and specifically Sirmium. Much of the major building project that occurred in Sirmum are thought to date to the 3rd and 4th century which bridged both a period of increased stress followed by economic surplus and stability.

The implication of the urbanization and size increase over time sets Sirmium in a prime theater for disease. Furthermore, movement of trade, whether via a system of roads that directly set Sirmium on cross roads between the eastern Provinces and Rome, or the Sava River would have brought disease vectors directly in contact with the population living in Sirmium.

There is a scarcity of information pertaining to periods of stress that are directly related to Sirmium. However, more general writings do describe periods of extended stress in Pannonia and indirectly Sirmium. For example the second half of the 2nd century marks period in Pannonian history that is rife with conflict. In 162 AD Marcus Aurelius' begins his reign and is almost immediately engulfed into war that directly affects the Province of Pannonia. Over the next 20 years there is hardly a few consecutive years that Pannonia is not in some sort of conflict. The extent of stress this placed on the civilian populations is unknown.

Moreover Mócsy (1974) and Barkóczi (1980) both suggest that the end results of the Macromanni Wars during the reign of Marcus's Aurelius' had great consequences Pannonia. Based on historical sources, Mócsy (1974) points to the mass removal of the provincial population by the warring German or Sarmatians of which approximately 150,000 people were returned at the closing of the war. Furthermore food resources including large number of cattle were also removed adding to the stress of war on the Pannonian population. It is not clear at this point as to the consequences of these events on the populations of Sirmium or for that matter the population of Pannonia; however, Barkóczi (1980) suggests that this war was most devastating to Pannonia. Other stressors including plague (small pox) were present in Sirmium but again there is no discussion on the effects on the population. Historical and archaeological evidence are normally used to corroborate these events in time.

Large scale events such as the Macromanni Wars occurred at different periods throughout the Roman Period in Sirmium but questions about the actual population in Sirmium have gone unanswered. Large scale immigration, periods of increase in disease, invasions, mixture of

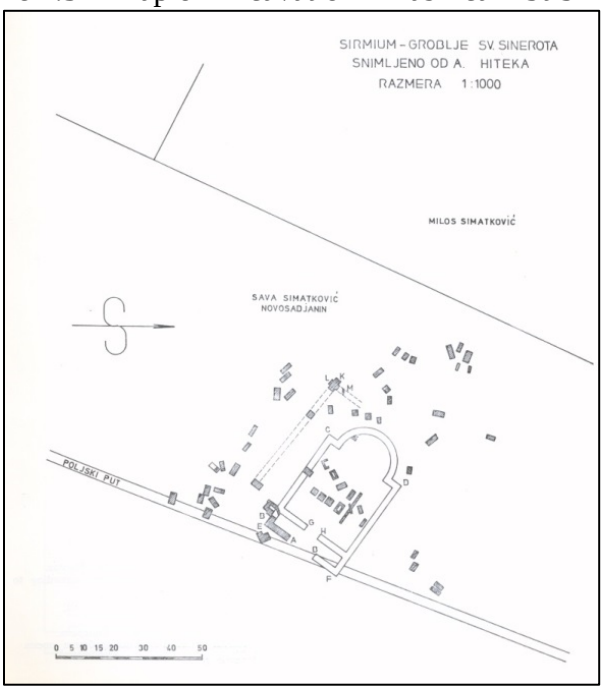
cultures and people from all over and outside the Empire would have direct influence on the Sirmium population and while assumptions pertaining to an expected pattern of health and disease during periods of population increase, movement of people (large immigrations), or extended stress related to political conflict can be proposed, ultimately the only direct evidence will come from skeletal material.

2.2 Excavation of St Sineros Cemetery (Locality 26) 1882 – 1970

The skeletal material utilized for this dissertation has its origin in the St Sineros Cemetery (Locality 26). This section will offer some background regarding previous archaeological work and some of the findings related to the major excavations occurring between the late 19th century and those that produced the skeletal material in 1969 and 1970.

Excavations carried out by Hyrek in the late 19th century were the first explorations of the St. Sineros cemetery (Milosevic, 1971). Hyrek's work was primarily focused finding the location of the Basilica associated with St Sineros.

Figure 2.3 – Map of Excavation – Basilica – St Sineros



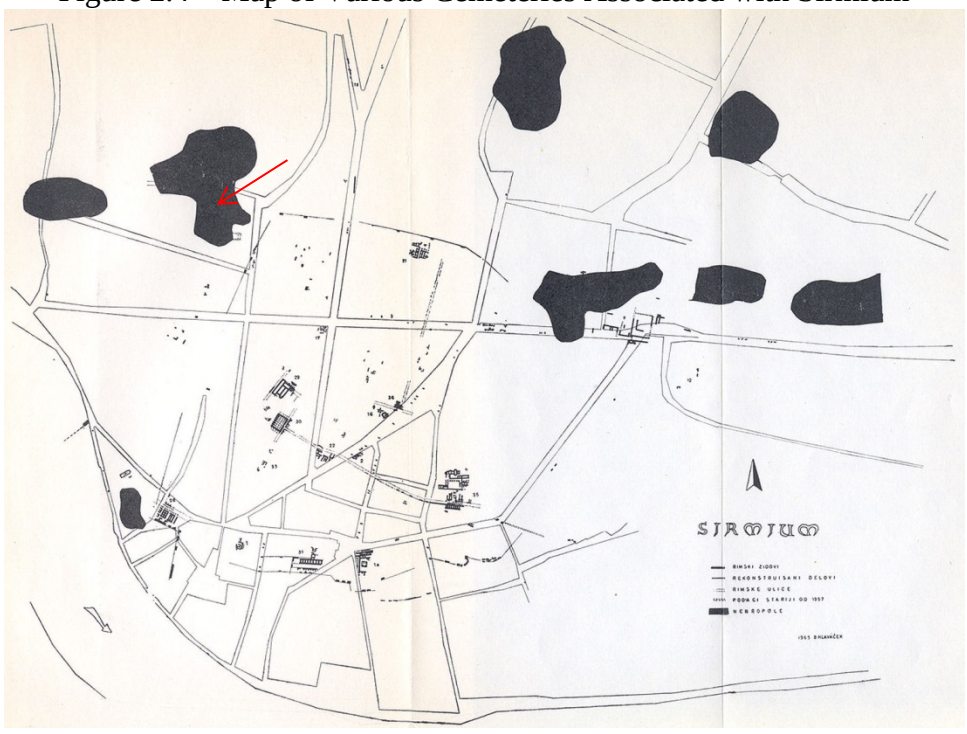
Map of excavation by Hyrek's of the Basilica within Locality 26
Source: Sirmium Volume 2 (1971)

According to Milosevic (1971), there were a number of tombs excavated around the Basilica (see Figure 2.3) but, unfortunately, there were some lapses and inaccuracies in the recording of the findings, including information pertaining context. The relative and absolute depths of the tombs described by Hyrek were not recorded and therefore potentially limited the temporal assignment for the graves. Approximately 70 years later, Jung (see Milosevic 1971) was able to, by association, use artifact dating and similarity tomb classification, to aid in the placement of them material from Hyrek's work on the northern most section of Locality 26, into a specific time period.

Based on the date associated with a single coin (Valens), a date of 4th century is suggested for the Eastern most cemetery and as it is thought to be, based on tomb style, associated with the northern part of Locality 26, which therefore suggests that the material excavated by Hyrek dates

to the 4th century. This date fits relatively well with the material utilized for this dissertation and the overall temporal period that the St. Sineros cemetery is thought to have been used. In addition to some of the problems associated with this particular early excavation, there is no information specifically stating whether or not any skeletal material was identified, removed and or analyzed. According the maps as a result of the in the 1969-1970 excavations at Locality 26, the basilica is located between ~25m and ~100m from the northern edge of the most northern soundings excavated during the 1969 – 1970 St. Sineros field work (see Figure 3.3). The tomb structures described by Hyrek indicate that there were a number of types of mortuary structures utilized in the most northern section of Locality 26.

Figure 2.4 – Map of Various Cemeteries Associated with Sirmium



Map of cemeteries surrounding the Sirmium
Locality 26 (St Sineros): red arrow.
Source: Sirmium 1999

Figure 2.4 exhibits the presence of at least seven of large cemeteries located on the outside of the Sirmium urban center. It is not clear from the excavated material or documentation available at

the time this dissertation was composed, whether or not and if any of these cemeteries were utilized during the same time period, with the exception of the eastern Roman Cemetery (see Milosevic 1971) or were they simply used as others filled to capacity.

Chapter 3

Materials and Methods

3.1 Introduction

This chapter will discuss the skeletal sample in terms of context, including the spatial and temporal distribution of the skeletal material within the cemetery, and methods use for the demographic analysis (age, sex, etc…). In addition the grave types, artifacts, and mortuary practices will be detailed as they relate to non-adults at Sirmium. All contextual information (with the exception of ^{14}C dates) is derived from the original paper work, which included grave descriptions, excavation depths, artifact information, original photographs, and site and individual burial plans. The general methods used for pathological analysis will be discussed in Chapter 4 and more specifically in Chapter 5 associated with the specific pathological conditions assessed for this thesis. It is noted that there is an abundance of original excavation paperwork that was compiled between 1969 and 1970, but it was found to be, in many cases, to be incorrect with conflicting depths for the same skeleton, photographs not matching burial plans, as well as descriptions of skeletons that did not match the burial sketches or photographs. As a result of these problems some of the original information had to be viewed with caution.

3.2 Demographic Information – Age and Sex Determination – Methods

3.2.1 Age determination – Bone and Dentition

Estimation of chronological age is one of the fundamental analyses needed prior interpreting skeletal data on health and disease. The calculation of age for non-adults was based on bone and dental development utilizing maximum length (MxL) long bone measurement, epiphyseal fusion, and dental eruption and crown formation, and then compared to a set standard. Due to the

incompleteness of many of the skeletons from the sample all methods listed above could not be readily used for each case.

Maximum length measurements, of all complete and unfused long bones, were taken using a sliding digital caliper or osteometric board (see Appendix B for a list of all long bone measurements). Measurements were then either converted into chronological age using an element specific linear regression formula for fetal, perinate and neonates or for older non-adults, the measurements were compared to a standard age chart. Protocol for taking long bone measurements were based on Buikstra and Ubelaker (1994) and measurement tables and linear regression formulas were based on those found in Scheurer and Black (2000).

In addition to a metric approach to age using the MxL of long bones, dental eruption patterns and crown formation, based on standards found in Buikstra and Ubelaker (1994) were also utilized. The use of dental material has been found to be a better measurement tool for age determination, due to the fact that development (eruption and crown formation) of teeth are affected to a lesser extent by stress when compared to bone (Larsen 1997; Hillson 2005). Both crown formation and dental eruption were used where applicable. Due to the protocol for the use of the Sirmium material unerupted teeth were not removed from the crypts and only those teeth that were observable were assessed for crown formation.

While the completeness of the union between epiphysis and the shaft of long bones was primarily used to calculate fusion age, other material including cranial material, vertebrae, bones of the pectoral and pelvic girdle were utilized as a method for age determination based on fusion.

The state of fusion was based on standards found in Buikstra and Ubelaker (1994) and then compared to fusion charts in Scheurer and Black (2000).

3.2.2 Sex Determination Methods

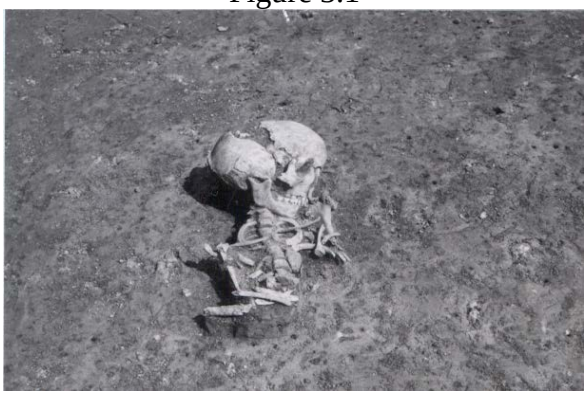
No attempt was made to determine the sex of non-adults with the exception of the older adolescents (16+), due to the lack of development of the regions, pelvis and skull, that display the greatest amount of sexual dimorphism. While some studies have tested the use of the mandible (Schutkowski 1993; Molleson et al 1998) and greater sciatic notch (Schutkowski 1993) for sex determination in non-adults, including individuals less than one years of age, there is not clear consensus on the practicality or reliability of these methods specifically for juveniles and some studies have shown the lack of correlation between regions of sexual dimorphism (mandible and pelvis) and correct sex identification (Vlak et al 2008). In the case of the older adolescents, the sub pubic region and greater sciatic notch were utilized according to Phenice (1969) and Buikstra and Ubelaker (1994), respectively.

3.3 Bone and Dentition Preservation

A variety of phenomenon contributed to the current preservation of the skeletal sample from Sirmium and more specifically to the material utilized for the research. Locality 26 cemetery was in use for approximately 600 years during which it clearly expanded and was altered by later the Roman construction of the northern wall of the city and defensive ditch. It is clear from the original photographs taken at the time of excavation that some of the burials had been disturbed thereby leading to missing portions of individual skeletons (see Figure 3.1). In addition to missing skeletal material, truncated burials resulting from consistent usage of the cemetery often

lead to post-mortem damage to the bones and teeth. Furthermore, the location of the excavation, in the vicinity of modern homes, often lead to part of complete skeletons being left in the excavation wall (see Figure 3.3a). This practice of removing part and leaving the remaining section of the skeleton in the trench wall, consequently also left some of the information on the particular burial behind in the excavation wall.

Figure 3.1



Grave 298: Child skeleton with distal ½ truncated

The preservation of the individual skeletons ranged from very complete to mostly incomplete (only a few bones representing an individual). The relative completeness of individual bones also had a wide range of preservation with some material being mostly complete and in good condition and at the other end, having some elements that were less than 10% complete. The lack of specific bone elements or dental remains and the state of preservation of individual bones teeth, in some cases limited the type of analyses that were performable. Preservation of smaller more fragile bones, as indicated by the presence of fetal material, suggests that the soil in which the material was buried was largely conducive to bone and dental preservation.

3.4 The Sample - Results

One hundred and two non-adults were analyzed for this dissertation. The skeletal material was excavated during two field seasons in 1969 and 1970. This sub-sample is part of a larger group

of skeletal material that in total represents approximately 285 individuals. Table 3.2 displays the distribution of individuals used for this dissertation according to age category. The following age categories were utilized for this thesis are based on those detailed in Scheurer and Black (2000) and are depicted in Table 3.1. Throughout this dissertation general age categories are used in discussions which does not necessary allow for cross comparison by other researchers. A full list of all individuals with associated numerical ages is found in Appendix A.

Table 3.1 – Age Categories and Age Ranges

AGE-CATEGORY	CHRONOLOGICAL DESIGNATION	BEHAVOIRAL DESIGNATION
FETAL	IN UTERO	NONE
PERINATAL	BIRTH	PRE-WEAN[1]
NEONATE	BIRTH - 1 MONTH	
INFANT	2 MONTH - 1 YEAR	
CHILD 1	1 YEAR - 5 YEARS	
CHILD 2	6 YEARS - 14 YEARS	POST-WEAN
ADOLESCENT	15 YEARS - 17 YEARS	

[1]Child 1 age categories contains individuals that are members of the pre-weaning and post-weaning age group

3.4.1 Age Distribution of the Sample

Age determination was calculated using a variety of methods (see above). The distribution of individuals according to age category for the sample can be found in Table 3.2. Individuals between the age of 1 and 14 (Children age category) were present with highest frequency (79.41%) when compared to all other age cohorts. The difference between the child cohort (CH1 and CH2) and all other individuals was found to be significantly different (Yates Correction χ^2=68.255 df=1; p=<.0001). Children were divided into two subgroups Child 1 (CH1) aged between1-5 years of age and Child 2 (CH2) aged between 6-14 years of age and represented 20.58% and 58.82%, respectively, of all individuals in this sample. This division was used to distinguish between those individuals that are often at a higher risk of morbidity and or mortality (1-5 years old) as compared to others within the particular age cohort. Pair-wise comparison

between the two child sub-groups was found to be statistically significant (Yates Correction χ^2=35.654 df=1; p=<.0001).

For some analyses specifically having to do with pathology and dietary analysis the sample was also separated into pre-weaning and post-weaning age individuals. Weaning age (pre-weaned) individuals accounted for slightly more than 33% (n=34) of all non-adults with post-weaning individuals comprising the remaining 66% (n=68). The difference between these behaviorally defined groups was found to be statistically significant (Yates Correction χ^2=21.353 df=1; p=<.0001). The age distribution of the material is suggestive of survivability into the older child group (6-14), during which there is a significant increase in the number of individual CH2 members appearing in the cemetery sample.

Table 3.2 – Age Distribution of the Sirmium Sample

AGE CATEGORY	COUNT	% OF N[1]	PRE-WEAN & POST-WEAN
FETAL	6	5.88%	33.33%[2]
PERINATE	3	2.94%	
NEONATE	2	1.96%	
INFANT	2	1.96%	
CHILD 1	21	20.59%	
CHILD 2	60	58.82%	66.67%[3]
ADO	8	7.84%	

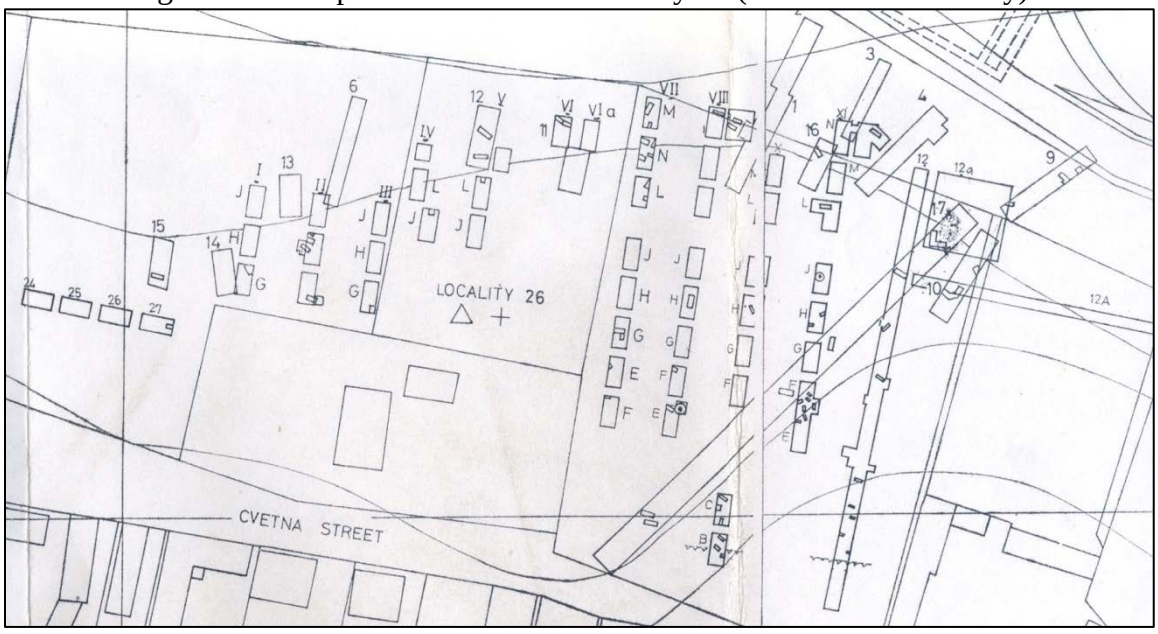
N[1]=102; [2]Percentage out of pre-weaning age individuals; [3]Precentage of post-weaning age individuals.

3.4.2 Non-Adult Burial Distribution

The non-adult skeletal material used for this dissertation was excavated from all soundings with the exception of sounding 6 and 6a (see Figure 3.3 for location). Distribution of individuals across the cemetery related to age-category is presented in Table 3.3. Based on the material recovered, there does not seem to be a pattern of distribution according to age, with the exception of the CH1 cohort. The majority of the 21 individuals from this age group were excavated from

the more western soundings of the cemetery. When compared, the difference between the prevalence of CH1 graves in the eastern and western parts of the cemetery was found to be significant (Yates Correction χ^2=9.524 df=1; p=.0020). The difference between the distribution of CH2 individuals was found not be significant with a relatively equal number of CH2 burial in both cemetery regions (Yates Correction χ^2=.300 df=1; p=.5839). It should be noted, however, that the statement made concerning the distribution of the different age categories within Locality 26 should be taken with caution due to the small sample and the relatively long temporal period the cemetery was in use. Furthermore, according to the original unpublished documentation concerning the excavation of Locality 26, only 25% of the cemetery was excavated during the two field seasons.

Figure 3.2 – Map of Excavation of Locality 26 (St. Sineros Cemetery)



Key: Excavation trenches for 1969-70 are labeled using Roman Numerals except for trenches 12, 12a and 12A
Note: Each sounding is represented by a number and 'letter' (ex. XM) and with the exception of 12, 12a and 12A all measure 5 meters by 2.5 meters
Source: Sirmium Volume 1: 1971

Table 3.3 – Distribution of Individuals –According to Sounding – Locality 26

	DISTRIBUTION OF INDIVIDUALS ACCORDING SOUNDING AND AGE CATEGORY												
A-CAT	S1	S2	S3	S4	S5	S7	S8	S9	S10	S11	S12	S12A-EXT-E	S12A-EXT-QUAD
FET	0	0	0	0	0	0	1	0	2	0	0	2	1
PERI	0	0	0	0	0	0	0	0	1	2	0	0	0
NEO	0	0	0	0	0	0	0	0	2	0	0	0	0
INF	0	0	0	0	0	0	0	0	1	0	1	0	0
CH1	0	0	1	1	1	1	1	0	9	2	1	3	1
CH2	3	1	3	3	3	6	7	6	8	9	0	5	6
ADO	2	0	0	0	0	2	1	1	2	0	0	0	0
TOTALS	5	1	4	4	4	9	10	7	25	13	2	10	8
% OF N	4.90%	0.98%	3.92%	3.92%	3.92%	8.82%	9.80%	6.86%	24.51%	12.75%	1.96%	9.80%	7.84%

Key: A-CAT= Age Category; FET=Fetal; PERI=Perinate; NEO=Neonate; INF=Infant; CH1=Child 1; CH2=Child 2; ADO=Adolescent

3.4.3 Grave Types

The non-adult sample was interred in two main grave types, those with additional structural components and those buried in simple shaft graves with no additional structural components. While there are references to cremation and some burnt material was recovered, no juvenile material used for this dissertation was the result of cremation. Evidence for this practice was found to be present alongside non-cremated material during the same time period, pointing to both mortuary practices being utilized at the same time.

Grave markers have been identified from this cemetery (see Mirkovic, 1971); however, there are no records of them being directly associated with any of the graves from the 1969-1970 excavations, as they were likely removed prior to any excavation during the 20th century. From the ones that have been published thus far, no references to children have been identified.

Of the 102 individuals used for this dissertation 54 (52.94%) were inhumed in identifiable graves. The remaining 48 individuals did not have information pertaining to grave type, the burial information was incorrect, or in some cases the material was disturbed. Disturbed material

was often listed as a skeleton that was pushed aside as a result of re-use of the cemetery during the Roman Period.

Of these 54 identifiable graves, 41 (75.92%) were simple shaft graves and 13 (27.7%) retained some evidence of structural components (brick-lined, stone floors, coffins, etc…) (see Table 3.5). Children comprised slightly less than 86% (n=47) of all individuals buried in graves irrespective of the type of interment, with adolescents accounting for slightly more the 9% (n=5) and infants comprising 3.7% (n=2) of material associated with graves. Fetal, perinatal, and neonates were not associated with any grave types. Other than individuals from the child cohort (CH1 and CH2) no other individuals were found to have additional structural components associated with the primary grave shaft.

Of the 81 children (CH1 and CH2 cohorts) present in this sample, 58.02% (47) were found to have been buried in identifiable graves with the remainder of children either without documentation of grave type or were found as disturbed deposits. Of these 47, children between the ages of 1-5 (CH1) accounted for 22.27% (n=10) of the members from this cohort that were inhumed in graves. The majority of children buried in graves were found to belong to the CH2 cohort; representing 78.23% (n=37) of children with graves. The difference was found to be significant (Yates Correction χ^2=28.766 df=1; p=<.0001). Additional structural components associated with graves were found in 13 of the 47 child graves. Of these 13, 5 (38.46%) were from children between the ages of 1-5, with the remainder associated with CH2 individuals (61.53%). The difference was found not to be significant (Yates Correction χ^2=.615 df=1; p=.4328).

Coffins, identified based on the presence of coffin nails, were found to be the most prevalent (n=8: 61.53%) type of mortuary structure for children. Graves with partial walls were associated with two children (see Figure 3.3 a-b), while one child's grave retained 3 flat stone tiles that were place on top of the individual without any other structural components. Two of the 13 children were found interred in tomb structures (see Figure 3.3 c-d). One was composed of flat paving stones without any mortar (c) and one was removed from a vaulted tomb (d). In the case of the vaulted tomb and the rectangular tomb, bone material from other individual was also recovered suggesting that the at least in the case of the vaulted tomb, the child might not have been the primary burial, so caution is needed when interpreting these burials.

Figure 3.3 a-d (Left to Right)

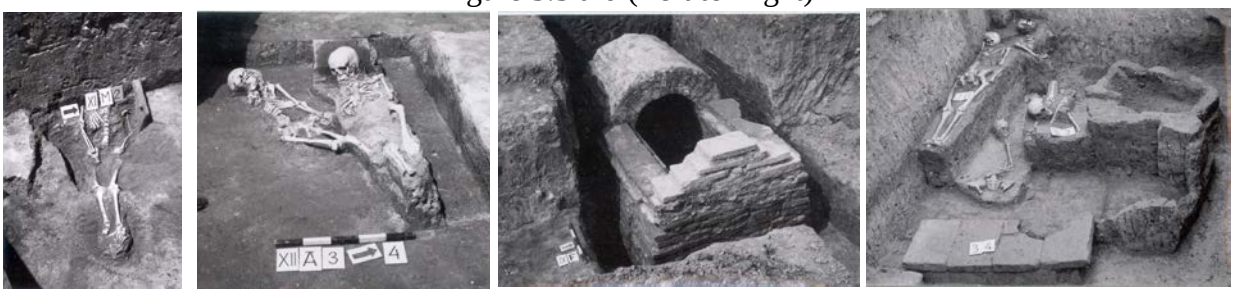


Figure a: Partial Tile Wall with proximal 1/3 in wall of trench; Figure b Stone Head Rest; Figure c: Vaulted tomb; Figure d: Stone slab tomb

3.4.5 Mortuary Artifacts

The presence of grave goods is solely related to the original grave descriptions documented at the time of the excavation. All artifact material remained in Serbia after excavation and was not available of assessment or analysis. In some cases photographs taken at the time of excavation helped to verify written documentation of the association between the artifacts and the skeletal material. Of the 102 non-adults 17 (16.6%) were found to have associated material grave

artifacts (see table 3.5). Slightly less than 65% (11/17) of those with artifacts were individuals from the CH2 cohort with CH1 comprising 36.36% and INF and ADO individuals both accounting for 9.09% of individuals buried with artifacts. All 17 individuals were interred in identifiable graves with 41.17% (n=7) of those inhumations having some evidence of mortuary structures. The remaining 10 interments were only observed to have simple grave shafts with no evidence for additional grave structures.

The most common category of artifact recovered was jewelry which was found associated with 10 of the 17 (58.82%) individuals, followed by coins, containers, and weapons which accounted for 29.41%, 23.52%, and 5.88% of the artifact types, respectively. Graves with multiple artifact types (i.e coins and jewelry) were found to be associated 4 of the 17 (23.52%) individuals, all of which were between the ages of 6 and 14 years of age (CH2).

3.5 Cemetery Chronology

According to (Mirkovic, 1971) most of what is currently understood about the history and archaeology of Sirmium can be dated to the later Roman Empire and that not much is known about early Roman Period (2^{nd}-3^{rd} centuries) in Sirmium. This at least partially due to the fact that the modern City of Sremska Mitrovica currently sits on top of the ruins of ancient Sirmium.

The cemetery, Locality 26, the focus of this dissertation, until now, has been dated using only artifacts, ceramics, coins and stratigraphy. Coins, artifacts and other chronologically sensitive material suggest that Locality 26 was in use between the 1^{st} and the 6^{th} century AD, which fits well with the fact that the Roman occupation of Sirmium mirrors this time span. Relative dating

techniques (stratigraphy) show that the majority of the excavated segment of Locality 26 date from the 4th century AD. Of the 324 recorded graves (adults and non-adults), 85 (~26%) contained material that was of use for creating a temporal framework for the grave. Based on the original documentation 1st, 2nd, and 3rd century burials comprised a smaller percent of the total datable graves compared to graves dated to the 4th century AD. Making up an even smaller percentage was 5th and 6th cemetery graves.

The majority of the burials in which artifacts were used to estimate their chronological placement within the cemetery were dated using coins. These particular burials represented ~53% or 44 graves dated by non-radiometric methods. The remaining 47% were dated using ceramics, fibula, and glass artifacts. The type of grave, the structural form, was not used as method for constructing the temporal framework for the cemetery.

3.5.1 ^{14}C Dates

In addition to the chronology suggested by the funerary artifacts, human bone samples were submitted for ^{14}C analysis (see Table 3.4). In 2005 and in 2007 a total of nine human bone samples from Locality 26 were submitted to the SUREC Radiocarbon Laboratory (see Appendix C for complete information on the ^{14}C results and Laboratory Codes) in Scotland for ^{14}C analysis.

The selected skeletal samples were largely from the eastern part of the cemetery (soundings 8 through 12a). No bone material was submitted from soundings 1-7. Further clustering of the samples was employed by selecting four samples from skeletons from sounding 10. The remaining material were from burials in soundings 8, 11, 12A-NW and 9N-EXT. The reasoning

for this sample selection was to more accurately date one part of the cemetery and then extend these dates to the western segment based on related stratigraphic layers and associated artifacts.

The ^{14}C dates ranged from the 1st to the 6th century AD which supports the archaeological and historical evidence for both the occupation of Sirmium and the use of the St. Sineros Cemetery. The fact that there is no evidence of any burials dating prior the Roman presence in Sirmium or after it was abandon in the 6th century suggests that the burials and skeletal material from Locality 26 falls within the Roman occupation. This statement is not meant to confirm that all individuals buried in this particular cemetery were 'Roman' it is only meant to indicate the temporal framework for the use of St Sineros Cemetery.

Table 3.4 – C14 Dates for Locality 26 Cemetery

SubSP#	AGE	C/N	C14-RCYRS	C14-ER	C14-R1SIG	C14-R2SIG
10-H-2-180-B8J-1	16	3.4	1720	35	240-410	250-390
10-C-9-172-S100-1	7.24	3.5	1705	35	250-420	250-400
10-M-NA-NA-B3B2-1	6.25	3.2	1725	40	230-420	250-390
10-M-13-201-S102-1	7.03	3.2	1770	35	130-380	210-340
11-J-4-225-S106-1	9.28	3.1	1700	35	250-420	260-400
11-N-9-251-S110-1	12	3.3	1705	35	250-420	250-400
12A-NW-QUAD-1-286-S109-1	6.75	3.5	1695	35	250-420	260-410
8-J-67-130-S107-1	7	3.2	1900	35	20-220	55-135
9-N-EXT-32-153-S118-1	16.13	4.7	1645	35	260-540	340-510

Key:C14 RCYRS=C14 Radio Carbon Years; C14 ER=C14 Error is +-; C14-R1SIG=C14 1 Sigma; C14-R2SIG=C14 2 Sigma

Early period graves from Locality 26, based on artifacts and ^{14}C analysis do not exhibit a pattern showing the earliest graves closest to the northern wall of the city. Nor do they exhibit a pattern in which the earliest use of the cemetery was near the road leaving the northern side of the city. This factor means that we cannot use the placement or the organization of the graves as a method for tentatively (relatively) drawing or creating a chronology of the cemetery.

Table 3.5 – Distribution of Artifacts and Grave Structures

BCINV	A-CAT	AGE	BP	DP	#OF ART	ART-CAT	ART-TYPE	ART-MATERIAL	GRAVE TYPE	GRAVE STRUCTURE TYPE
12-QUAD 6-1	INF	0.25	NO	NA	1	CONT	TOILET BOTTLE	GLS	NO-STRUCT	
11J-5	CH1	1.75	NO	NA	1	JWRY	BEADS; NECKLACE	GLS; BRO	STRUCT	COFFIN
10M-1	CH1	1.75	YES	YES	1	JWRY	COIN PENDENT	BRO	NO-STRUCT	
10C-1	CH1	2.67	YES	YES	1	JWRY	BELL	BRO	STRUCT	COVERED WITH 3 BRICKS
12ASW-QUAD -1	CH1	5	YES	YES	1	MONE	COIN	BRO	STRUCT	COFFIN
11EF-EXT-1	CH2	6	YES	YES	3	MONE; WEAP	COINS; KNIFE; GLASS	BRO; IRO; GLS	STRUCT	VAULTED TOMB
7G-1	CH2	6.083	YES	YES	1	JWRY	RING	BRO	NO-STRUCT	
10M-6	CH2	7.03	YES	YES	1	JWRY	BRACELET	BRO	NO-STRUCT	
11M-1	CH2	7.313	YES	NA	2	JWRY; MONE	BRACELET; COINS	BRO	STRUCT	STONE WALL
9N-EXT-1	CH2	7.8	YES	YES	2	JWRY; OTH	BRACELET; LAMP	BRO; TER (CER)	NO-STRUCT	
11J-1	CH2	9.45	YES	YES	1	JWRY	BEADS; NECKLACE	GLS; BRO	STRUCT	COFFIN
11F-1	CH2	11.75	YES	NA	2	JWRY; MONE	BRACELET; COINS	BRO	NO-STRUCT	
5K-1	CH2	12.46	YES	YES	1	CONT	GLASS BEAKER	GLS	NO-STRUCT	
7G-4	CH2	13.5	YES	YES	1	CONT	FLASK	GLS	NO-STRUCT	
7G-3	CH2	13.75	YES	NA	1	MONE	COIN	BRO	STRUCT	COFFIN
8F-1	CH2	13.8	YES	YES	1	JWRY	BEAD	TER (CER)	NO-STRUCT	
7F-3	ADO	16.13	YES	YES	1	CONT	BOWL	TER (CER)	NO-STRUCT	

KEY: A-CAT=Age Category; BP=Bone Pathology; DP=Dental Pathology; #OF ART=Number of Artifacts; ART-CAT=Artifact Category; NA=Not Applicable; CONT=Container; JWRY=Jewelry; MONE=Money; WEAP=Weapon; OTH=Other; GLS=Glass; BRO=Bronze; Ter=Terracotta; IRO=Iron; CER=Ceramic; STRUCT=Structure

3.6 Mortuary Practices

In accordance with Roman Burial Law (i.e Twelve Table Laws) (see Toynbee, 1971), which dictated that human burials must be position outside of the city, Locality 26 cemetery formed on the outskirts alongside the northern edge of the city. Burials dated between the 1st to the 3rd century at Sirmium, for the most part, follow this pattern with some differences seen in the 4th century with evidence for burials with in city walls. This material was not part of this dissertation, but may nonetheless exhibit a shift in burial law or may indicate burial associated with wealthy individuals or families.

Roman mortuary practices varied considerably according to time period, geographical location within the empire, age and sex of the individual, and status of the deceased. Treatment of the body fell in to three main categories: 1. Cremation; 2. Inhumation; 3. Embalmment (Toynbee, 1971; Morris, 1992). At Sirmium, archaeological excavations have identified two of the three main types of burials; cremation and inhumation.

As noted above, none of the material used for this dissertation exhibited evidence for cremation and while this might suggest that this particular rite was not used or ceased to be used any more, evidence for cremation was identified the form of cremated bone, and the burnt walls of some graves. Based on the original documentation from the excavation, the cremated material had been burned in place without being deposited into any type of vessel (i.e urn). The very limited amount of cremated material was examined for evidence of non-adults. The fragments of bone, which were few, were too thick (long bone shaft fragment) to have come from a child or infant;

and while it is possible that the material came from an older adolescent, there is not enough evidence to support this statement.

Death rituals which includes burial practices are ultimately for the living (Morris, 1992), and are primarily controlled by cultural views on mortality in addition to the need to dispose of the body, as it posed a real threat to the physical and spiritual health of the living. Toynbee (1971) and Morris (1992) give in depth discussions on Roman death ritual and grave types for different classes of the Roman population during the Empire with less of a focus on the Republic. As such a detailed description of the general practices will be limited in this dissertation. Furthermore, only a small number of references were made which were associated with the burials of non-adults in these reference books.

Evidence of Roman burial ritual, only comes to light through a combination of archaeological and bioarchaeological evidence and historical documentation which together provides the potential for the most holistic picture of the mortuary ritual associated with children and other non-adults from the Roman Period. It is important to understand however, that the graves types, mortuary items found in associated with the deceased children and other non-adults, and the location within a cemetery are controlled not by the deceased but by the living and not in all likelihood by children.

Evidence for the differential burial treatment, in terms of type and location, of children and other non-adults has been identified in Roman Period cemeteries in various regions of the Empire (Norman, 2002). Segregation of children and infants from the main cemetery population has

been found at Thysdrus in Tunisia (Norman, 2002) as well as at Lankhills cemetery in Britain (Gowland, 2000), both dating to the Roman Empire which, according to Norman (2002) is a reflection of the Roman ideal that children are different from adults within Roman society. This however, while the placement of children in Roman society may be founded, there is also evidence to the contrary, suggesting that children and infants shared a similar status to adults, related to burial type, grave goods and location, within the realm of the dead. At Poundbury, a Roman period cemetery utilized from the 1st to the 4th century AD in Britain, excavation of 1200 skeletons revealed that burials of children showed no differences in terms of grave type or artifacts, when compared to the adults within the same burial group or family plot (Molleson, 1989). Differences were found however, between family groups suggesting that while members of the same family shared a similar burial status comparisons across the cemetery showed that burial status was not necessarily equal (Molleson, 1989).

The mortuary rituals, as they come to us from historical documents and funerary monuments (headstones and sarcophagi) suggests that the ritual associated with the death of children and other non-adults did in fact differ when compared to adults (Huskinson, 2007; Toynbee, 1971). This included the length of mourning, which was correlated to age of the infant/child and generally amounted to a shorted period of grief compared to adults. Toynbee (1971) suggests that the death ritual of children and infants was a private matter for the family and was therefore, conducted in privacy at night. Treatment of the body (inhumation/cremation) was also restricted by age of the individual particularly in the case of infants. Individuals between 0 and 6 months were, according to Pliny (*Natural Histories 7.15.72*), writing in the 1st century AD, not be cremated as there would be nothing remaining of the individual after cremation and would be

therefore in conflict with beliefs in the afterlife. Unfortunately, the aspect of the ritual associated with the death of a child or other non-adult groups evaluated for this thesis cannot be securely identified with respects to the Sirmium material in part due to a lack of contextually associated funerary monuments or headstones or historical documents specifically regarding treatment of deceased non-adults in Sirmium.

As discussed in chapter two, defining of childhood, infancy and adolescence is a difficult task being that they are culturally derived terms in which their very core is directly associated with a specific culture, time period and geographic region. The artifact material retrieved from the graves of non-adult individuals at Sirmium does not exhibit any significant differences when compared to adult burials with the exception of one grave. Items of jewelry, containers, and money have all been identified in the graves of adults. Only one exception was found; the small bronze bell that was found associated with BCINV10C-2, a child approximately 2.76 years old. Bronze bells have been found associated with the burials of children in other Roman period cemeteries (see Norman, 2002) but have also been found in adult burials as well. Fitz (1980), however, briefly mentions that education was a part of the childhood in Roman Pannonia, making reference to historical documents and the presence of an inkwell in the grave of child but does not indicate clearly the cemetery in which the grave was located. No such items were recorded for any of the graves at Sirmium.

3.7 Sample Limitations

As with any cemetery sample, it is just that: '*a sample'* and as such is not a complete representation of the population. Limitations that directly affected the analysis of this sample are

largely related to skeletal completeness, preservation, missing documentation, incorrect labeling and recording of skeletal material in terms of grave location, depths and basic demographic data all of which occurred at the time of excavation. Some of these inconsistences in the original paperwork were resolved using photographs taken at the time of excavation which helped to place some of the skeletons in the correct spatial location within the cemetery. Other inconsistences were not readily correctable especially related to depth measurements (stratigraphic location), which are especially important when attempting place an individual within a temporal framework. In the case of the Sirmium material, due to the lack of or incorrect labeling of material, some skeletons could not be directly associated with a specific time period (1^{st} century, 2^{nd} century, etc…), and therefore had to be relocated to a temporal period that spanned the entire use of the Locality 26 (i.e 1^{st} – 6^{th} century). These factors along with, in some cases, a mixing of skeletal material was taken into consideration during the analysis of the non-adults. The limitations associated with demographic analysis including interpretation of skeletal stress in archaeological populations are addressed in primarily in Chapter 4 in the section on the 'Osteological Paradox'.

Chapter 4

Pathology

4.1 Introduction

Disease is an overreaching term used to indicate a state of physiological impairment within the body. Maladies of all types have plagued humans from the very earliest of our ancestors, and have continued to develop and adapt alongside of our species up until the modern day. In this sense, the evolution of humans is intimately intertwined with disease (Baum and Kahila Bar-Gal, 2003). As a result of this relationship, it is of vital importance to understand both the modern scourges but also human disease in antiquity. Human paleopathology, which can broadly be defined as the study of disease in ancient humans (Ortner, 2003; Aufderheide, and Rodriguez-Martin, 1998), largely embraces this task of identifying disease in the ancient human remains.

4.2 Differential Morbidity

Not all segments (i.e age, sex status) of population are equally at risk for exposure and development of disease. Infants and children represent a segment of a population that has an increased risk of morbidity and mortality when compared to other segments of a given population (Goodman and Armelagos, 1989; Lewis, 2007). Recent estimates point to at least 10 million infants and young children between the ages of 0 and 5 years of age dying due to infection each year (Black and Bryce, 2003). In modern populations the risk of morbidity and mortality, associated with disease, for this specific segment of the population varies according to the geopolitical environment and economics of the region. Furthermore, cultural and biological, both as intrinsic and extrinsic phenomenon have the potential to increase or decrease the risk

factors directly or indirectly related to disease contraction and disease progression in infants and children.

High infant and child mortality is likely to have been a reality in ancient societies, including that of the Romans. Moreover, the disorders that are responsible for the large proportion of sickness and death in modern populations are likely to have been the same for the Roman Period infants and children. Currently, the largest number of infant and child deaths are attributed to gastrointestinal (diarrheal) and upper respiratory infections (Cotran et al., 1999; Black et al., 2003). It has been suggested by a number of authors (Ortner, 2003; Waldron, 2009; Mays, 1998) that these disorders were likely to be the agents responsible for elevated morbidity and mortality for individuals between 0 and 5 years of age in ancient societies.

It is clear from modern data on infant and child mortality that multiple infections, in addition to poor nutrition are often found in the same individual. Based on the International Classification of Diseases only a single etiology is listed as the cause associated with an individual's death and therefore the presence of other co-existing are disorders is likely to be underestimated in the risk of death. While the consequences in terms of modern health (see Black et al., 2003) is not necessarily a primary concern with regards to this dissertation, the presence of more than one disorder muddies the connection between diagnosis of disease and 'cause of death' for paleopathology.

From a biological standpoint, infants and young children are physiologically less likely to be able to mount an effective response to infectious pathogen due to the fact that their immune

system is still developing. This is further aggravated during the weaning period when they are removed from the passive immunity supplied by breast milk. Culturally dictated limited or no access to nutritious foods during weaning the period and or restrictive diets also have the potential to increase risk of deficiencies (i.e. iron) but also to elevate risk of morbidity and mortality associated with infectious pathogens. Adequate supply of vital nutrients during early life is necessary to compensate for the amount of pressure early growth places on the metabolic processes associated with growth and development (Ortner, 2003). Moreover, the symptoms of and consequences of some disorders (i.e. scurvy) will be more severe when compared to adult individuals, specifically because of the metabolic demand required by the body during the early growth period (Ortner 2003) is greater when compared to individuals who have completed growth.

This connection between all of these variables, while inherently complex, has been described by Goodman and Armelagos (1989); clearly showing the interrelatedness between human biology, the natural environment and culture as they relate to disease in skeletal remains. The connection between biology, culture, exposure risk, disease development risk, and mortality risk will be a common theme throughout the remaining chapters of this dissertation.

Before attempting to understand the specifics of disease affecting infants, children, and adolescents from Roman Sirmium and the broader bioarchaeological picture, it is important to first gain insight on some fundamental basics of bone and dental pathology both from a clinical and paleopathological perspective. Moreover, issues related to paleopathological analysis and

interpretation will also be discussed as this particular area can and does significantly influence what can be said about disease in ancient society.

While this dissertation is not the format for a full discussion on the definition or categorization of disease it should be noted that there is not sense of unity within clinical pathology (and medicine) with regards to these two key factors (see Humber and Almeder 1997) and as a result of this ambiguity there is a rippling affect in the discipline of paleopathololgy. This disparity will become clearer in the discussions below.

4.3 Clinical Diagnosis

Clinical diagnosis of disease is based on external observations with some (most) cases an array of invasion and non-invasive laboratory tests (Waldron 2009). In addition to the full range of x-rays, MRIs, blood tests, and newer genetic tests that aim to complement the physical examination, modern clinicians often have to opportunity to discuss potential symptoms with the patient and the all so telling patient statement of 'it hurts here when I do this'. The accumulation of these elements should, in most cases, lead to some type of diagnosis or cause for the aliment suffered by the patient. This ideal, however, is not always met in modern medicine and more often than would be expected, is often incorrect, leading to more complications and in some cases to the death of the patient (Waldron, 2009). The relationship between modern clinical diagnosis and paleoapathology might seem as distant as the thousands of years that often separate the archaeological population from the modern patient, but in hindsight, the difficulties in diagnosis of a specific disease or pathogen are in most cases exponentially more complicated, often ending in a non-diagnosis, (for a specific pathogen or casuistry agent) in paleopathology.

4.4 Bone and Dental Disease – Basics

4.4.1 Bone

Bone is often seen as an unchanging solid structure which is far from the true. It is dynamic structure that grows and atrophies in response to both normal and abnormal stimuli. It protects our vital organs as well as serving to give form to the soft tissues and provide the attachment for muscles and thereby allowing for movement. It also is the storage of red marrow and later in life yellow marrow, while also participating in the immune system (Cotran et al., 1999; Ortner, 2003). With the many functions bone performs it is a wonder that it is limited in the reaction to disease.

Bone is a composite material consisting of both an organic and an inorganic component. Collagen forms >90% of the organic portion (approximately 20% of bone) while hydroxyapatite (a salt) forms approximately 80% of bone (Ortner, 2003; Resnick, 2002). The rigidity and plasticity of bone is directly related to its biochemical make-up (organic/inorganic components). While it is important to understand, in detail, the biochemistry and microscopic composition of bone in relation to bone pathology, this dissertation is not the proper platform for an in-depth discussion. A more detail discussion on this topic can be found elsewhere (see Resnick, 2002; Ortner, 2003).

4.4.2 Teeth

The chemical composition of teeth is largely comprised of the same biological tissues found in bone but in significantly different proportions. Additionally, unlike bone, visible changes to the structure or gross morphology are often readably observable to the living individual. These

changes which include, dental wear (attrition), cavities, periodontal disease, calculus and enamel defects, are to some extent at the root of phrase ‘Show me your teeth, and I will tell you who you are’. More specifically, diet, environment, and individual behavior all play a role in the basic morphology and the pathological conditions affecting the teeth.

Teeth are comprised of three distinct tissues; enamel, dentin and cementum. Of these, the former two are the primary sources for information in dental studies in bioarchaeology and paleopathology. Enamel, found on the outer surface of the tooth crown, is the hardest substance in the human body and the only biological material to naturally and normally mineralize (Hillson, 2005). The main component of enamel is the inorganic salt hydroxyapatite. Making up a much smaller percent is the protein collagen.

The physical and metabolic properties of teeth make them a key target of biological tissues for analyzing the early development record of individuals using chemical (isotopic) analyses. Furthermore, the lack of remodeling of enamel also allows for the macroscopic and microscopic study of a permanent record of dental disease (barring extrinsic variables), specifically in the form of enamel defects, for an individual.

Teeth are often the most resilient part of the human body in terms of survivability in the archaeological record. This property often leaves them as the only part of the skeleton that is recoverable from archaeological contexts.

4.5 Limiting Factors in the Diagnosis and Classification of Bone and Dental Disease in Paleopathology

Disease is a process and what is observed on the skeleton is a 'snapshot' of this process. As such, the event, in this case the pathophysiological event, must be recreated from what is understood in clinical pathology, but also in terms of the pathophysiological capabilities of bone as it reacts to disease. There are a variety of limiting factors that influence diagnosis in paleopathology, more specifically with regards to bone disease. Within this group of limitations two main areas require further discussion. The first has to do with the limited physiological responses bone has to stimuli.

Pathological changes in bone represent a part of a continuum in which physiological disruption caused by intrinsic or extrinsic phenomenon directly or indirectly affects the normal homeostasis of bone metabolism (Resnick, 2002). According to Ortner (2003), these changes largely fall into three main categories: 1. Abnormal increase in bone 2. Abnormal decrease in bone and 3. Abnormal quality of bone. The processes that lead to net increase or decrease in bone can be placed into generalized categories (see Table 4.1) which indicate the imbalance between bone growth and bone loss.

Table 4.1 – Bone Pathology

Category of Bone	**Bone Type Quantity**	**Net Bone**
Normal Bone Growth $\longrightarrow$	Abnormal Decrease Bone Loss $\longrightarrow$	Net Increase in Bone
Abnormal Increase Bone Production $\longrightarrow$	Normal Bone Loss $\longrightarrow$	Net Increase in Bone
Normal Bone Growth $\longrightarrow$	Abnormal Increase Bone Loss $\longrightarrow$	Net Decrease in Bone
Abnormal Decrease Bone Growth $\longrightarrow$	Normal Bone Loss $\longrightarrow$	Net Decrease in Bone

Table is based on information from Ortner 2003

The creation or removal of bone (pathology), as noted above, is part of a process, of which might be the result, at least initially, of an infective agent (pathogen) and while these pathogens play a

role in the net increase of decrease of bone, they actually rarely directly affect bone, but rather disrupt the hormones responsible for the balance of these two processes (Resnick, 2002).

In most cases in paleopathology the bone disease as it appears on the skeleton, is non-specific, meaning that lesions result from abnormal bone growth or abnormal bone loss are not pathogemonic of a specific pathogen or disease.

Second area of concern relates back to the earlier section of diagnosis. From as early as the 19th century there has been a connection between clinical pathology and paleopathology (Jarcho, 1966). This connection has become a fundamental step in the identification and etiology of pathological lesions affecting the skeleton. Paleopathology still largely relies on clinical diagnosis and classification of bone disease (Ortner, 2011; Waldron, 2009), which incidentally has been found to be less than perfect (Waldron, 2009). As such, the problems incurred in modern medical diagnosis and disease classification (see below) are inadvertently transferred to paleopathological studies, making identifying the specific etiology of skeletal pathology more difficult.

To add to the compounding limitations suffered by modern clinicians, plaques of woven bone (often referred to as periostitis or periosteal bone), a common finding and readably observable on archaeological skeletal material are often missed or not observable on standard X-rays and are therefore, not recorded in modern clinical cases are being part of a specific disease process caused by a specific disorder. Therefore, when these types of lesions are observed on

archaeological skeletal material, paleopathologists do not have a modern pathology reference to relate them to.

In addition to the issues regarding disease identification and the connection to modern clinical pathology, Waldron (2009) makes the very relevant point that there is a lack of standardization among paleopathologists with regards to a 'system of diagnoses'. To this must be added that terminology within this field used to describe and categorize disease is far from homologous. For example in conducting research on disease for this dissertation it was found that certain diseases were classified differently depending on the individual(s) conducting the research and or writing the article/book. A few examples should suffice to shed some light on this issue. Anemia, which will be discussed in more detail in below, is not necessarily a disease but rather it is a consequence of an underlying phenomenon leading to a decrease in circulating RBCs. It has, however, been classified as a nutrient deficiency (Roberts and Manchester 2005), metabolic disease, and blood disorder (Resnick, 2002; Ortner, 2003). These classifications are found both in paleopathology and modern clinical publications. This lack of cohesiveness within paleopathology makes it more difficult to conduct cross or inter-population studies in which the data on disease was compiled by different researchers. More recently, steps have been taken to address issues related to standardization in terminology and disease classification (see Buikstra and Ubelaker, 1994; Ortner, 2011), but it is clear that work within this particular area still needs to continue.

4.5.1 Disease Diagnosis – Potential Answers

The challenge of diagnosis in paleopathology due to the limited response bone has to stimuli can be, in part, overcome through accurate description, carful comparison of ancient examples of pathology with modern samples, and an understanding of the disease process responsible for producing the specific types lesions (Ortner, 2003; 2011). Moreover, accurate contextual, (local and global), demographic (age, sex, ancestry, etc…) and cultural (socio-economic, access to food, etc…) information can greatly enhance the outcome of disease identification and diagnosis. Newer diagnostic tests, including the use of ancient DNA (aDNA) can help to identify specific pathogens (i.e *Mycobacterium tuberculosis*) or to differentiate between the biological sex of individuals (Faerman, 1998; Brown, 2001; Mays and Faerman, 2001). While there has definitely been an increase in the use of these methods over the last 5 to 15 years, ethical consideration, expense and issues of contamination, still hamper and limit the overall use of aDNA as a standard method. MicroCT and thin sectioning have also been employed to help with identification and diagnosis of disease in paleopathology with some success (Schultz, 2001 but see Waldron, 2009 for criticism) but run into some of the same potential pitfalls as aDNA. This dissertation did employ thin sectioning of bone on a limited basis thin sectioning with some success.

One can easily be swept up in the possibility of a '*magic bullet*', whether in the form of an extracted microscopic molecule or a 100 *um* section of bone that will spit out a diagnosis, thereby alleviating the sometime monumental level of frustration that accumulates in trying to identify the pathological agents responsible for the lesions found on ancient skeletal material. It is important to note, however, these methods should be used in collaboration with standard

macroscopic description or accurate literary sources and archaeological contextual information, as was the approach taken, where applicable, in this dissertation.

4.5.2 Disease Diagnosis in Infants and Children – Specific Age Related Concerns

As children and other non-adults are the focus of this dissertation, one more issue regarding disease in bone needs to be addressed. Areas of bone growth in the form of woven or periosteal bone are a common finding on the skeletons of infants and young children and can be mistaken for evidence of pathology. The periosteum is responsible for producing bone, increasing the diameter of long bones, during normal growth and development so again it would be a not uncommon finding on the skeleton of infants and children. In addition to normal deposit of bone, the periosteum is also responsible for producing bone as a result of pathology. Morphologically (macroscopic and microscopic) there is no difference between woven bone deposited as the result of normal growth or pathology. Here, age plays an important role in distinguishing between normal and pathological bone. According to Ortner (2011) the presence of woven bone on the skeleton of individuals younger than 2 years of age is likely to be a normal part of growth. Periosteal bone on the bones of older (>2 years of age) children is more than likely to be the result of pathology. There are some exceptions, however, to this particular parameter. Extensive bone growth outside of the normal range for infants and children younger than 2 years of age can be the result of pathological processes as was found in at least two individuals from this collection.

Furthermore, individuals with evidence of skeletal or dental lesions are thought have been able to mount some sort of physiological response to stress. As compared to those children that died

without lesion formation, it is thought that they were not able to mount a response to the pathogen and therefore were not as strong, in the sense of having the ability to ward off pathological agents.

4.6 Paleopathological Analysis – The Osteological Paradox

Description and diagnosis are some of the primary goals of paleopathology and therefore should form the foundation for statements made regarding the broader picture of health in past populations. As with other areas of paleopathological research discussed above, the step of making sense of raw data collected on skeletal pathology and being able to make statements regarding health and adaption on a population scale, as has some inherent risks of its own which require further discussion.

Notwithstanding the issues pertaining to disease identification, Wood et al., (1992) address three areas of paleodemography in which interpretation of skeletal disease was found to be more complicated then was once thought. Even so, some the areas of concerns were identified prior to prior to the publication of the Osteological Paradox (see Ortner, 1989). The first, demographic non-stationarity points to the fact that because populations are not stationary (i.e. no migration), patterns of mortality derived from cemetery populations say more about fertility rates than they do about frequency of death (Wood et al., 1992; Wright and Yoder, 2003). They are not representative of a living population because they are dead and were at a higher risk for death than those that lived.

It has been is abundantly clear for decades that cemetery samples represent a very select and biased group of individuals; the non-survivors. This fact ties into the second area of concern raised by Wood et al., (1992). The second point raised was one of 'selective mortality', which introduces the idea that mortality rates given a specific disease process will be higher among the dead of a given age affected by the disorder and therefore overestimate the prevalence of a given disease process for the whole population. More specifically, lesions identified on the skeletons of individuals within a specific age group do not reflect the risk of death for all individuals that lived passed that particular age. It should be noted however, that lesions (healed) or chronic lesions, are those that occur or began prior to the death of the individual and therefore should be viewed not necessarily as a cause of death but as a part of the individual's disease history and only a segment of the continuum of the disease process.

The last issue is that Wood et al., (1992) describe is that of hidden heterogeneity of risks. All individuals within a population are at some sort of risk for disease and death. Some of these risks vary and ultimately underscore the individuals overall frailty and probability of contracting a disease and succumbing to death. Wood et al., (1992) suggest that these risks are hidden and therefore do not allow for accurate interpretation of population based mortality rates as they relate to age. The list given by Wood et al. (1992) of hidden risks does not necessarily have to remain hidden. Differential diet as identified though chemical analysis, differences in treatment of males vs females, and the use of mortuary practices can all be used to create a foundation that will allow for the identification of these 'hidden' risk factors. Tackling the problems associated with hidden risk and frailty for groups of individuals within a population is obviously more complicated than described above, but the point here is that some of the risks can be identified if

the correct questions are asked. Some of these risks are discussed in this chapter and in later chapters (see chapters 6 and 7).

4.7 Paleopathology – General Methods Used for Analysis

All skeletal and dental material that was used for this dissertation was examined macroscopically and microscopically for specific pathomorpholical features associated with categories of disease including infection, metabolic and hematopoietic disease. Standard protocol for the description and recording of bone and dental pathology was utilized, as suggested by Buikstra and Ubelaker (1994), Ortner (2003) and Waldron (2009) with some alteration. Modern and archaeological references samples currently housed in the Department of Anthropology and Archaeology at Brooklyn College were used, when applicable, for comparison. All pathological conditions were described in detail, photographed, and entered in to an MS Access database.

In addition to the standard macroscopic analyses, small samples of material were subjected to standard X-Ray, Multi-Slice CT imaging for visual analysis of specific pathological specimens and conditions. Lastly, thin sections produced at the Hard Tissue Research Unit Laboratory at the NYU School of Dentistry of orbital and cranial vault material were created specifically to assess cribra orbitalia, porotic hyperostosis and endocranial periosteal bone growth. A full report on this material will be forthcoming in a separate publication and only specific examples of this project will be discussed in this dissertation. Details concerning the specific methods used for paleopathological analysis will be discussed in Chapter 5 associated with each pathological condition that was evaluated for this thesis.

4.8 Specific Disease Categories – Bone

4.8.1 Infectious Disease – Periostitis

Bacteria, viruses, protozoa, are classes of microorganisms capable of causing infectious disease in humans (Cotran et al., 1999; Resnick, 2002; Mitchell, 2003). Infectious disease is defined as being caused by specific pathogens (bacteria, viruses, etc…) capable of, via the specific organism or through the toxins produced by the specific microorganism, being transferred from one human host to another (Cotran et al., 1999; Sattenspiel and Slonim, 2012). To this, however, it must be noted that infectious disease in humans can also be transferred from non-human animal to human host (i.e *Mycobacterium bovis*) and then onto another human host. These types of infectious diseases are often classified as zoonoses (Brothwell, 1991).

These classes of pathogens have invaded the human body for thousands of years acting as agents of natural selection thereby influencing the evolution of our species (Inhorn and Brown, 1990; Colwell, 1996; Larsen, 1997; Baum and Bar-Gal, 2003) through, in the simplest view, an adaptation arms race. In actuality, however, our interaction and 'co-evolution' with infectious pathogens is much more complex, involving variables founded in culture, individual biology, and the environment. From the stand point of disease in general, many of these internal and external variables that factor into individual susceptibility are no different than those that are in play when evaluating non-infectious disease in modern human or ancient populations and will be discussed in more detail below.

There are numerous variables that are simultaneously at play, actively increasing or decreasing an individual's risk of exposure and or contraction of a pathogen, and thereafter, progression to a

disease state. Individual genetic make-up, demographic placement (age and sex), culturally dictated behavior (i.e. trade, diet, access to food, warfare), environment, and climate, all, either individually, but more likely in combination with one or more variables, potentially play a significant role in the susceptibility of an individual to be infected by one or more of these types of pathogens. This is discussed in more detail by Cohen (2000) in relation to emerging infectious disease modern populations, but the key factors, which include both host (cultural and biological factors) and pathogen (co-evolution) changes, discussed can easily be incorporated into discussions regarding the presence of infectious pathogens in ancient populations including that of the Roman period in Sirmium. Irrespective of specific etiology, it is clear that throughout human history human choices and behaviors have often been the initial spark that ignited and or intensified the relationship between pathogen and human (Colwell, 1996).

Population Specifics

Within all populations, specific groups are often a greater risk for exposure to infectious pathogens and consequently have an increased morbidity and mortality as a result of initial exposure. Infectious disease ranks at the apex for cause related to child morbidity and mortality in modern populations (Black et al., 2003) and likely held the same position in ancient society.

Infectious Disease – Infants and Children

Infants and young children represent a segment of modern and ancient populations with elevated risk for exposure and contraction of infectious pathogens. This risk is linked to various intrinsic and extrinsic factors including but not limited to physiological development, shift in behavior patterns (weaning), access to adequate nutrition, and socio-economic status. Goodman and

Armelagos (1989) discuss two major periods in which morbidity and mortality of infant and young children exhibit a higher frequency; 0-1 years of age and the weaning period. While, infectious disease is not the only culprit during these age sensitive times, it remains a significant factor, especially during the weaning period and immediately after. Diarrhea and other gastrointestinal disorders caused by infectious agents are currently a major cause of child death (Larsen, 1997; Cotran et al., 1999; Black et al., 2003) and were likely to have been equally or more devastating in antiquity.

Of key importance during this age (≤ 5 years of age) is the shift from breast milk which contains passive immunity, to solid food which often has less nutritional (protein) value. According to Black et al., (2003) individuals between the age of 0 and 5 years of age that are not breastfed show an increase risk for mortality when compared breastfed infants and children of the same age cohort. Furthermore, Victoria (2000) notes that in a recent study it was found that there is a significant elevated risk for infant mortality from infectious disease within the first two months for individuals not breastfed as compared to those that are. Interestingly, she also notes that risk increases with an increase in age even for those children that are consuming breast milk and is likely to be partially the result of the incorporation of 'complementary' food sources (weaning foods). The identification of this shift is possible in archaeological material using stable isotopes (see Chapter 6). As such, this change from weaning to post-weaning behavior not only often negatively affects child nutrition, but also exposes the individual to pathogens found in weaning and post-weaning foods and potentially increases infectious disease prevalence. As discussed in previous sections there is a significant relationship between poor nutrition and elevated infectious disease. In addition, the incomplete development of the immune system of infants and

young children, pose a significant risk during periods of exposure to infectious pathogens, heightening the chance for contraction of a particular infectious pathogen and progression to a state of physiological impairment. Prolonged periods of physiological disruptions, or stress, caused by infectious pathogens can lead to pathological changes in the skeleton and dentition of infants, children and adolescents.

Infectious Disease – Classification in Paleopathology and this Dissertation

The system used to classify infectious disease is one that is broadly used in paleopathology and bioarchaeology (Mays, 1998). It is largely based on the inability to identify a specific pathogen(s) as causative agents in the morphological changes observed on the skeleton. In actuality, the lesions that are observed to be associated with infection are in fact caused by a specific pathogen(s) but due to the standard physiological response of bone to invasive organisms in most cases it is not possible to differentiate between causative microorganisms (Roberts and Manchester 2005). Diseases in which a specific pathogen cannot be identified will be classified under the broad category of Non-Specific Infectious Disease (NSID). According to a number of researchers (Larsen, 1997; Ortner, 2003; Roberts and Manchester, 2005), the bacteria often responsible for pathological skeletal changes primarily include members of the follow genera Staphylococci, Streptococci, Pneumococci, and Salmonella. The pathological changes in bone that result from NSID are often similar to those observed in Specific Infectious Diseases (see below) making distinction between these categories of infectious disease difficult to differentiate. In addition to the complications, originating with the limited response of bone to infectious pathogens and as such the difficulty differentiating between NSID and SID based on skeletal lesions, the more than often incompleteness of archaeological skeletal remains makes

using lesion distribution, in many cases, impossible to utilize for linking lesions with a specific pathogen and disease (see below for more in depth discussion).

Infectious Disease – Non-Specific Infectious Disease – Skeletal Manifestation

NSID are most often subdivided into those infections that affect the external surface bone and those that involve the internal cavity of bone. Periostitis represents a type of NSID that causes abnormal lesions on the external surface of the bone while osteomyelitis shows evidence for both the periosteal and endosteal surface being affected (Larsen, 1997). Additionally the cortex of the bone (between the internal and external surfaces) can also be subject to infection leading to osteitis. Due to the lack of evidence in the Sirmium collection for osteomyletis in children and other non-adults only periostitis will be further discussed in detail.

Periostistis as suggestive by its name involves the periosteum, a membrane that forms an intimate layer surrounding the surfaces of bone, except on articular surfaces. The periosteum, retains the ability to produce new bone throughout life even after growth has ceased (Ortner, 2003). As a result, insult to this membrane will activate this physiological property and produce new bone which is then added to the external cortex.

This disorder is therefore characterized by surface formation of bone on the outer bony cortex (Roberts and Manchester, 2005). These plaques of abnormal bone growth during the active phase are initially loosely attached, with clear border and a porous woven appearance (Lewis, 2007). Periosteal lesions, if healed will have been remodeled into to the underlying cortical bone. Periosteal bone formation is not pathogenic of a specific disease and can be a symptom of a

variety of infectious diseases, including but not limited to tuberculosis, syphilis, and leprosy. Non-specific periosteal bone formation is one of the most common pathological finding on archaeological skeletal material (Ortner, 2003). These lesions have been identified on a variety of skeletal cranial and post-cranial elements.

In addition to affecting the external surface of the bone through the properties of the periosteum, the internal membrane of the cranium has similar properties allowing for the production of new bone formation throughout life (Mensforth et al., 1978; Lewis, 2004), which allows for the abnormal deposit of bone on the internal surface of the cranium. This dissertation will use the term periostitis to describe abnormal bone formation on the endocranial surface of the bone of the skull (see below).

Infectious Disease – Specific Infectious Disease – Skeletal Manifestation

In contrast to NSID, specific infections are those in which the causative pathogen is identifiable (Roberts and Manchester, 2005). The skeletal manifestations associated with SIDs are, in many cases, morphologically the same as those associated with NSID. The main difference is that the pathogen responsible for the lesion is identifiable. Moreover, some specific infectious diseases display a patterning, or specific distribution of lesion. This, while helpful, will not allow for a diagnosis. This factor clearly is a limiting consequence, rooted in the limited responses bone has to pathology.

Of the many infectious agents likely to have caused disease in humans, relatively few specific pathogens have been identified in archaeological skeletal material. This drought of identity rests

on a number of interrelated variables including but not limited to pathogenesis of the disease (i.e some diseases do not affect bone), the virulence of the pathogen and the age of onset.

Infectious Disease in the Roman Empire

Evidence of for infectious disease during the Roman Empire (post 1st Century AD) comes in the form of 2 main types of evidence; 1. Historical writings and 2. Skeletal Evidence. Of these categories, which incidentally can be split into sub-categories, the only primary evidence, as with all paleopathology, comes from the skeletal remains (including dental material).

Within the category of historical writings, evidence for infectious disease can either be in the form of direct or indirect evidence, with direct being specifically pertaining to incidences of disease. These, however, are largely related to large scale epidemics (or pandemics: see Fears, 2004) and do not necessarily relate to specific segments of the population (i.e children) or smaller scale geographic regions. Documentation of disease largely fell into the hands of practicing physicians, emperors, and or biographers. Indirect evidence, for infectious disease in historical writing, must be extracted from events that are likely to be associated with increase of infectious disease. Famine, warfare, and large population movements (i.e migrations), all of which might not be recognized out right with increases in mortality and morbidity, can be used as supplemental information regarding infectious disease.

It is clear that there was understanding during the Roman Period of interest in this dissertation, that infectious disease was present. This not only included infectious agents leading to epidemic during the mid to late 2nd century (probable small pox outbreak), but also could be related to the

more endemic pathogens such as the malaria parasite. Interestingly, it is thought that public health programs (draining of large bodies of standing water) specifically related to malaria were undertaken during the 1st and 2nd century AD by both Trajan and Hadrian to quell morbidity and mortality related to malaria (Hart, 2001). The draining of swamps directly associated with Sirmium was conducted in the 3rd century AD by the Emperor Probus. While suggested to be a method to increase agricultural land, this practice associated with Sirmium could have inadvertently decreased mosquito population and the spread of infection. More recently evidence for specific infectious disease (TB) has been identified using a combination of macroscopic and biomolecular techniques in Roman Britain and Pannonia (Mays et al 2001; Mays and Taylor 2002).

4.8.2 Hematopoietic Disorders – Anemia – Porotic Hyperostosis and Cribra Orbitalia

Anemia in the true sense, is not a disease, it is a symptom or consequence that is characterized by a decrease in the carrying capacity or in the quantity of red blood cells (RBCs) that delivery oxygen within circulatory system (Resnick, 2002; Cotran et al., 1999) as related to the age of the individual (Roberts and Manchester, 2005). As such, the manifestation of anemia in an individual can be result of a variety of disease processes that ultimately disrupt balance between production and destruction of RBCs which according to Walker et al., (2009) and Cotran et al., (1999), can be caused by acute blood loss (e.g. trauma); impaired RBC production or an increase in hemolysis. Ultimately these three primary causes can be put under two main headings; anemia with a genetic origin and anemia that are acquired during the life of an individual. Irrespective of the etiological origin, the presence of anemia is currently a world-wide phenomenon, with some estimates of, according to Ryan (1997), specific types of anemia affecting between 20 and 25% of sub-sections (infants) of the world population making a significant health concern across the globe.

As noted above, anemia can be classified as genetic or acquired. Genetic anemia such as sickle cell and thalassemia are hereditary in origin. Acquired anemia represents those types anemia that develop without relationship to genetic mutation and are often related to dietary deficiencies (ie iron, vitamin B12, folic acid) (Ortner, 2003), metabolic diseases, and or infectious diseases (Walker et al., 2009). Paleopathological evidence for both genetic and acquired forms of anemia have been identified in archaeological skeletal material from a variety of geographic regions (Angel, 1966; Mensforth et al., 1978; Stuart-Macadam, 1985; El Najjar et al., 1976). In the following sections, I will briefly discuss basic characteristics of some of the genetic and acquire

anemia, specifically relevant to paleopathology and bioarchaeology research. This is not meant to be a full scope of the types and clinical aspects of these types of disorders. For a more detail discussion on anemia see Cotran et al. (1999).

4.8.2.1 Genetic Anemia

Genetic anemia such as Sickle Cell Anemia (SCA) and Thalassemia (THA) are classified as hemolytic anemia. As a group, hemolytic anemia, share some common characteristics, including a significant reduction in the lifespan, as a result of premature destruction, of mature RBCs and, directly related to this phenomenon, a significant increase in the formation of RBCs (Cotran et al., 1999).

Both SCA and THA disorders are the result of mutations in Beta chain or Alpha or Beta chains, respectively. These differ in the foundation of the dysfunction, with the primary problem in SCA lies with the malformation of the shape of the Red Blood Cell (RBC) and THA stemming from in the production of hemoglobin (Ortner 2003). Both disorders, however, reduce the ability of the RBC to properly and adequately perform its primary objective; the transport of oxygen throughout the human body. Both disorders are characterized by a significant reduction in the lifespan of RBC in addition to a significant increase the production of RBC directly related to the initial premature destruction of RBCs (Cotran et al. 1999)

These genetic forms of anemia in heterozygous form confer some ability for the host to resist the malaria parasite, which is transferred via the mosquito. While resistance is present for individuals homozygous for these types of anemia, this allele combination is most often lethal

sometime after birth. As a result of the connection between the malaria pathogen and resistance offered by SCA and THA, individuals with these genetic disorders are often found in regions, such as the Mediterranean, (for more comprehensive list see Ortner, 2003), that are endemic for malaria. These forms of anemia are far rarer than those that are acquired (Walker et al., 2009).

4.8.2.2 Acquired Anemia –Iron Deficiency and Megaloblastic Anemia

Those anemias categorized as acquired result from a variety of non-genetic based phenomenon. In comparison to hereditary based anemia (ie. Sickle Cell and Thalassemia) acquired forms are much more common. Furthermore, unlike genetic anemia due to its primary 'balanced' relationship with specific geographic regions endemic for the malaria parasite, this class of blood deficiencies is globally more wide spread. As such, the basic origin for acquired anemia is equally diverse but can be, at a very general level, associated to two major categories; nutrient deficiencies and blood loss (see Walker et al., 2009).

Under nutrient deficiencies that lead to acquired anemia, this dissertation will explore Iron Deficiency Anemia (IDA) and Megaloblastic Anemia (MBA) as they relate to childhood pathological conditions such as Porotic Hyperostosis and Cribra Orbitalia. While the nutrient(s) responsible for the these types of disorders differ, both conditions share some similarities with regards to causes leading to the nutrient deficient state and etiology which will be described in more detail below. It should be noted, however, that both types anemia can potentially coexist in the same individual.

Iron Deficiency Anemia

The most prevalent type of nutrient deficiency, IDA, is primarily caused by insufficient dietary intake or malabsorption of iron, or significant blood loss (Ryan 1997; Cotran et al 1999). Iron is a vital component playing a role in the proper functioning of the immune system, the synthesis of the collagen (Roberts and Manchester 2005), in addition to aiding in normal cellular growth (Ryan 1997). Its primary purpose, however, is in the construction of hemoglobin and by association in the transport of oxygen throughout the circulatory system.

Dietary iron is found in both plants and animal as non-heme and heme forms, respectively. These forms of iron are, however, not absorbed equally. Plant based iron, is less easily absorbed as compared to animal based heme iron (Roberts and Manchester, 2005; Cotran et al., 1999). As such diets (vegetarian or vegan) with little to no animal flesh can potentially lead to IDA with supplemental intake of iron based foods.

Iron deficiency anemia, while not necessary fatal can lead to impairment of normal physiological processes (physical growth) in addition to negatively affecting cognitive and motor skill ability, especially in infants and children. It is during the periods of growth, both physically and mentally that there is an increase demand for iron directly related to an increase in the RBC production.

Megaloblastic Anemia

Megaloblastic anemias are largely caused by deficiencies in vitamin B12 or folic acid (Cotran et al., 1999; Walker et al.,2009). Both folic acid and vitamin B12 are not synthesized internally and

therefore must be obtained through dietary intake. Foliate acid is normally found in high quantities in green vegetables with lower quantities found in meat. Alternatively vitamin B12 is primarily found in animal flesh with only inadequate amounts in plants (Walker et al., 2009; Stabler and Allen, 2002; Cotran et al., 1999). Similar to IDA, the primary causes leading to these types of MBA, are dietary deficiencies and malabsorption, or significant blood loss.

In addition to leading to MBA deficiencies in foliate acid and vitamin B12 can lead to disruption in DNA synthesis (Cotran et al., 1999). Additionally, vitamin B12 deficiency can lead immune and nervous system dysfunction with some individuals having permanent developmental disabilities (Walker et al., 2009; Stabler and Allen, 2002).

Acquired Anemia Etiology

As discussed above the cause for types of acquired anemia mainly fall into three general categories; 1) dietary intake; 2) malabsorption; 3) significant blood loss. There is a stark difference in the complexity of the foundation of the etiology associated with acquired anemia compared to genetic anemia. The latter are fixed in that the disruption in the RBCs and by extension the carrying capacity for oxygen is predetermined by the genetic makeup of an individual with SCA or THAL. In contrast, the basal etiology for IDA and MBA is not fixed, having roots in biology, culture, and environment. Below I will discuss the factors that lead to problems associated with inadequate dietary intake and malabsorption of vitamin B12 and iron that in turn facilitate a pathway leading to anemic states associated with IDA and MBA.

Resource Access

Access to food is a consequence of two primary variables, environment and culture. An individual's access to resources that contain adequate quantities of vital nutrients, including vitamin B12 and iron, is likely to be controlled by a variety of complex and interconnected biological and cultural factors. Other than the actual environmental constraints that often limit or block cultivation or the raising of a food source, albeit there is always the possible to overcome this via trade, socioeconomic status, age, and sex either as individual entities or interconnected categories play significant roles in granting or restricting access to food.

Climate and environment, including soil types and altitude, influence the ability to grow crops and or raise livestock thereby potentially limiting access to specific categories of food. In addition, local geography, including proximity to coastal regions or fresh water in the form of lake and rivers, would also potentially dictate to some extent access to marine and fresh water resources (fish, mollusks, etc…). Natural disasters (drought, earthquakes, etc.) can potentially lead to a lack of access to food resources. Under these circumstances, limited food supplies would be available, and as such, intra-population differential access might occur and as a further consequence intra-family level differential access to food types might also come in to play. The limitations that the environment, climate and geography, put on the access to food can at least in part be overcome by human behavior (i.e. trade, land clearing, etc…).

Meat, the primary source of heme iron and vitamin B12 was a resource that during the Roman period was subject to differential access. This unequal distribution is found within multiple levels of Roman society. At a population level, meat was considered to be a higher status food (of

which different types were classified as more expensive) and therefore a higher consumption would be suggestive of a high socio-economic placement within society (Garnsey, 1999). It is also, thought that marine resources, specifically fish, and shared a similar placement to terrestrial meat. The differential access resulting from culturally backed rules regarding the distribution of sources high in B12 and iron within specific cohorts of a population are likely to put them at a higher risk for developing MBA and or IDA.

Women and children occupied a lower status with regard to food irrespective of socioeconomic status as compared to men, during Roman antiquity (Garnsey, 1999). This position dictated by culture and largely ignoring the physiological needs, would therefore lead to an unequal distribution of foods containing higher quantities of iron and B12, more specifically meat. According to Garnsey (1999), while this part of the Roman diet did not normally play a large role, it would have nonetheless been distributed to the 'producers' (i.e men) of the family first. This would have effectively left the females and children more at risk to develop megaloblastic and or iron deficiency anemia. In addition depriving women that were actively breast-feeding of iron and B12, the infants and young children that were still relying on nutrients supplied through breast milk were also at risk for developing these types of anemia (see below). Evidence for differential diets between men and women of the same population have been found in Roman period skeletal samples using carbon and nitrogen stable isotopes (see Chapter 6 for a more detailed discussion).

Diet – Choice

Standard dietary regime during the Late Roman Period consisted of a mixture of plant (cereals) and some incorporation of meat (Garnsey 1999). Diets that purposefully restricted consumption of animal products in some form (vegan and vegetarian), are therefore unlikely. These types of diet, however, if extreme could lead to both IDA and MBA especially in infants and young children or individuals still consuming breast milk of females that consume vegan or vegetarian diets. Identification of diets that largely excluded animal protein is possible using carbon and nitrogen isotopes (see chapter 6) but the reasoning (famine, cultural practices, choice, etc…) is not likely to be indefinable at the individual level without supporting resources. In fact, the isotopic results would be no different than an individual that did not consume B12 and or iron rich foods (animal products) as a result of differential social and or economic status or age related restriction.

Malabsorption

Individuals that consume diets that supply an adequate quantity of both iron and vitamin B12 still run the risk of developing IRA and MBA through malabsorption. Vitamin B12 and iron are absorbed in the intestines. Poor absorption of these nutrients can be the result of a number of factors, including parasitic infection (ring worm, roundworm, etc…), bacterial infection, chemical composition of plants, or deficiencies in other vital nutrients (i.e vitamin C). Within specific age segments, for infants and young children, of a population there is a greater risk for malabsorption as compared to older individuals. This additional risk is related to a combination of biological and cultural phenomena. In the following discussion, I will discuss the many variables associated with the etiology of IDA and MBA.

Weaning

As noted above, infant and young children are in general especially vulnerable for developing IDA and MBA due to the pressure put onto the RBC development to keep up with normal growth and development. The weaning period, however, represents a period in which the infant/child is at an elevated risk for developing nutrient deficiency based disorders, including IDA and MBA.

During weaning there is an increase potential in iron deficiency (Mittler and Van Gervan, 1994) as these individuals are introduced to weaning foods which are notoriously known to often times be nutritionally insufficient with regard to iron. The early weaning foods that were prescribed during the Roman Period were largely cereal based (Garnsey, 1999) and offered little amounts of iron and in addition, initially no vitamin B12. Furthermore, cereal based foods also contained components that actively inhibited the uptake of iron (see below) further enhancing the potential of iron deficiency. Combined with an increasing demand for iron, due to rapid growth during infancy (especially between 4 and 6 months old), after the fetal iron stores are depleted, the lack of weaning foods containing sufficient iron and B12 were likely to increase the risk for IDA and MBA in this particular group.

Adding to the potential for developing IDA or MBA, infants and children that begin to consume weaning foods are now at risk for exposure to new pathogens from external (non-breast milk) sources, including food and water. Gastrointestinal infections from food and waterborne pathogens are common causes for weanling diarrhea (Lewis, 2007) which in addition to being a significant cause of morbidity and mortality in modern and archaeological populations also have

the potential through diarrhea, to lead to IDA. Infectious agents also have the potential to lead to IDA through their relationship with iron (see below).

The dietary status of lactating females directly influences the nutritional status of breastfeeding infants and children (Victoria, 2000). As such, these females with inadequate iron intake, irrespective of the cause, will enhance the risk of the breastfed infants and children developing iron deficiency. This is further heightened when the fetal stores of iron have been depleted and there is a shift in reliance on outside sources of iron which includes both breast milk and weaning foods.

Malabsorption – Diet

There are a number of factors that will inhibit the absorption of iron, specifically non-heme iron, in plants. Phytates, chemical components found in a number of plants including, wheat, millet and maize act as an iron inhibitor. Diets high in these types of plants, without supplementation from other sources could lead to iron deficiency. Alternatively, in addition to including animal flesh, consuming foods that contain vitamin C or lactic acid will aid uptake of non-heme iron from these types of cereals (Larsen 1997).

Infectious disease/Parasitic Infection

There is some evidence to suggest that there is synergistic relationship between iron and some infectious pathogens (Larsen, 1997). It has been suggested that during periods of infectious caused by bacteria, the body mounts a physiological response in which iron availability is restricted and in doing so, the body deprives bacterial pathogens of iron, a component necessary

for their metabolism (Skaar, 2010; Blaschitz and Raffatellu, 2010; Kumar and Choundry, 2010). This relationship is, however, complex as bacteria have evolved mechanism to at least partially side step this defensive mechanism (see Skaar, 2010). This defensive response, if chronic, can lead to IDA, but according to Ryan (1997), would alternatively curb the more deadly outcomes of infectious diseases such as tuberculosis, caused by bacteria. It would seem that based on this 'adaptive' response to infectious pathogens, that if there is a high prevalence of IDA there should be the inverse in regards to the prevalence of infection. As noted above, some bacteria adapted to this defensive mechanism, so an inverse relationship between IDA and infection might not be observable in all cases.

Intestinal parasites, ingested though consuming contaminated meat, fish or water have the potential to lead to both MBA and IDA. According to Walker et al. (2009) parasitic infectious agents, such as giardia, pin worms and round worms all have the potential to negatively affect the absorption of vitamin B12 increasing the risk for MBA. Furthermore, hookworm infection can lead to intestinal bleeding and the loss of iron of which according to Scrimshaw and Sangiovanni (1997) less than ½ of the iron is re-absorbed. The large amount blood (and iron) lost during these types of intestinal infections can lead to IDA (Larsen, 1997).

Acquired anemia, specifically, IDA and MBA, are potentially caused by a number of factors. In the discussion above, the separation of the types of potential causes for acquired anemia should not be taken as grounds for a deterministic model as it is more than likely that the pathway leading to acquired anemia (IDA or MBA) in an individual rests on a complex interaction between human culture and biology and the environment and not a single isolated event.

4.8.2.3 Skeletal Manifestation of Iron Deficiency and Megaloblastic Anemia

Evidence from clinical cases in the form of radiographs and autopsies indicate that different types of anemia have the potential to cause pathological changes in the skeleton in both the cranial and post-cranial skeleton (Resnick, 2002; Ortner, 2003; Cotran et al., 1999). While there is overlap in the pathomorphology, the bony elements and the specific location affected there is often enough of a difference in these areas to allow for a narrowing down with regards to type of anemia that is potentially responsible for the observed skeletal characteristics. Further aid in this process can be gained from age and sex demographic information in addition to geographical and local environmental data (i.e regions endemic for malaria). In the sections below, this dissertation will limit its discussion to the skeletal manifestations as they relate to IDA and MBA except where is relationship to differentiation between other types of anemia. Additionally, the focus of the pathological skeletal changes will mainly target the cranium, albeit, the post-cranial skeleton has been identified as a region that can be affected as a result of anemia.

Acquired anemia (IDA and MBA) and genetic hemolytic type anemia (SCA and THAL) have the potential to cause morphological changes that target the vault bones of the cranium. These lesions, which affect the ectocranial surface of the vault, are referred to as Porotic Hyperostosis (PH). In addition to affecting the external vault, these types of anemia have also been implicated in the formation of similar porous lesions found on the orbital roof (formed by the frontal bone). Porotic hyperostosis and cribra orbitalia are some of the most common pathological conditions found in skeleton from archaeological sites (Walker et al., 2009; Lewis, 2007; Larsen, 1997) and therefore require a detailed discussion and understanding of the type of lesions characteristic of the disorder, the expected distribution, pathophysiology, and the proposed etiology. It should be

noted that PH recently has been used to describe vault bone lesions and Cribra Orbitalia (CO) has been used to describe lesion affecting the orbital surface. This format will be used in this dissertation.

General Lesion Morphology

There is some evidence of variation in the shape and size of the pores affecting the ectocranial surface of the vault. Morphologically, on the surface these lesions exhibit circular openings that can range from pinprick to >1mm in diameter. In more advance/severe cases these pores can become coalesced resulting in irregular shaped opening. In addition to the porous nature observed on the surface, in some cases evidence of trabecular bone can be seen extending above the normal level of the ectocranial surface (Stuart-Macadam, 1985). Radiographically these trabecular extensions, which are directly related to the resorbtion of the ectocranial surface, are characteristically known as 'Hair on end' (Stuart-Macadam, 1985). Further changes to vault bone include a thickening of the internal diploe related to increase in RBC production (see below) with as, noted above a thinning, and in some cases the loss, of the external layer of vault. Cribra Obitalia is represented by porous lesions that show similar morphological characteristics as those found to affect the cranial vault. As Stuart-Macadam (1989) notes the progression to more severe CO largely follows the patterning found in PH from individual pores to larger coalesced openings.

Porotic Hyperostosis is usually displays bilateral lesions affecting the ectocranial surface of the vault bones including the frontal, parietals and to a lesser extent the occipital (Stuart-Macadam, 1985; Aufderheide and Rodriguez-Martin, 1998). The areas of the vault affected by PH can vary

in size from a small affected zone to lesions covering much of the external surface of a specific bone. Similar to PH, CO lesions are usually bilateral and have the potential to cover much of the anterior one half of the orbital roof (frontal bone). In addition to the regional coverage, the density of the pores affecting the vault or orbital regions, which incidentally in likely related to the severity of the disorder, also show variation (see Stuart-Macadam, 1985).

It should be noted that pathological changes associated with genetic and acquired anemia have been found affect the post-cranial skeleton. According to Resnick (2002), the tubular bones of the hand and feet, have been found to exhibit evidence of mild marrow hyperplasia as a result of IDA. Lesions affecting the neck of the femur and humerus have been recently discussed in relation to acquired anemia (Djuric et al., 2008) but there is limited clinical data to confirm these findings. Genetic anemia (SCA and THAL) show more evidence for post-cranial pathological changes as compared to acquired forms of this disorder.

It has been suggested by Stuart-Macadam (1989) that lesions affecting the orbits represent an early stage of the PH and only more developed cases will exhibit vault surface lesions. The linear connection between orbital and vault lesions seems to be more complicated than was originally suggested as more recent work by Ubelaker (1992) on skeletal material from Ecuador showed a propensity for cranial lesions while Larsen (1997) notes that work conducted by Webb in 1995 concluded that porous lesions were found to affect the orbital surface in the majority of cases.

4.8.2.4 Pathogenesis of Porotic Hyperostosis and Cribra Orbitalia – Anemia

The pathological pathway that leads to the formation of external lesions on the vault and orbital surfaces is related to abnormal expansion of the inner table bone or diploe caused by marrow hyperplasia (hyperplasia being the enlargement of an organ). While it is rarely discussed in much to the publications on PH and CO, it is nonetheless, of significance to understand the patho-physiological process. This understanding will allow for a more accurate diagnosis or differential diagnosis.

The diploe of the skull consists of maze of trabecular bone interspersed by small spaces located between the individual bone struts. In life, these spaces are filled with red bone marrow, capable of producing new red blood cells (RBC). During early growth and development the medullary cavities of long bones and the diploe of the vault bones are the primary centers for erythropoiesis. During periods of decrease hemoglobin the body can become oxygen staved. This state of hypoxia triggers a hormonal response. The hormone erythropoietin stimulates the red marrow to produce RBCs and marrow hyperplasia. The increase in the quantity and in some cases the size of the RBCs leads to an increase in pressure on internal surface of the external layer of bone which ultimately leads to the resorption of both the trabecular and outer table of bone. The exact link between the buildup of RBCs and pressure that consequently leads to removal of bone is not currently known (Aufderheide and Rodriguez-Martin, 1998). Interestingly, Ortner (2003) notes that osteoclastic activity is more prevalent under conditions of active hyperemia and following this line of thinking, the increase in oxygenated blood under high oxygen tension could therefore trigger the increase in activity of osteoclasts during periods increase RBC production and marrow hyperplasia. The consequences of a hyperemic state would

seem to complement Aufderheide and Rodriguez-Martin (1998) discussion that the pressure from the increase in RBCs and marrow hyperplasia inhibits periosteal vessels capable of producing new bone.

The age dependent location of red marrow formation (the vault bones) and the preponderance of archaeological and modern cases would point to porotic hyperostosis being a disorder that is the result of severe anemia that occur at a developmental period when the diploe of the vault bones are a primary center of RBC production. This factor suggests that porotic hyperostosis and cribra orbitalia are likely to be conditions found in children and adolescents (Stuart-Macadam 1985; Walker et al., 2009; Lewis, 2007).

4.8.2.5 Porotic Hyperostosis and Cribra Orbitalia – Proposed Etiology

Porous hypertrophic lesions found on the ectocranial surface of the skull are regularly identified in archaeological skeletal collections. Although these lesions are essentially not specific indicators of stress, they have, nonetheless, been attributed to different forms of anemia and more specifically to anemia caused by iron deficiency.

Originally, PH was linked to genetic hemolytic anemias based on clinical cases of patients with sickle cell anemia and thalassemia. In the late 1960's Angel (1966) found PH in skeletal material from Greece to thalassemia. This was follow up by work done by Kennedy in 1984 on archaeological skeleton from South Asia. In both of the situations the geographic region in which these skeletal populations originated were in areas where they is evidence of endemic malaria. This bolstered the theory of thalassemia as individuals with one defective gene enjoyed partial

immunity from malaria. During the late 70s and early 80's work conducted pre-historic Native American populations produced high percentages of individuals with PH. Unlike the material earlier researchers used, the material from North America was not from geographical locations were malaria was a significant factor. As an alternative explanation for the cranial lesions researchers opted for an iron deficiency explanation related to diet.

Studies on pre-historic Native American populations linked these lesions with a dietary deficiency of iron based on the consumption of a maize based diet. Natural chemicals with in maize, phytates, naturally inhibit the uptake of iron (Larsen, 1997). A diet that in which the primary source of food is maize would likely induce iron deficiency anemia in the population. Alternate hypotheses including infection and parasite load have been suggested (see Larsen, 1997) but all are related to a deficiency in iron. It has been relatively ignored, however except by a few (see Ortner, 2003; Waldron, 2009; Lewis, 2007), that the marrow hyperplasia and the skeletal lesions PH and CO might not be related to iron deficiency anemia. Recently, Walker et al., (2009) discusses the general lack of pathophysiological evidence iron deficiency as the cause of PH and CO and instead suggested that these pathomorphologies are likely to be the result of megaloblastic anemia related to Vitamin B12 deficiency. The idea that iron deficiency cannot lead to PH or CO has more recently been challenged by Oxenham and Cavill (2010) suggesting that chronic iron deficiency during early growth can in fact produce lesions representative of PH and CO based on marrow hyperplasia.

Interestingly, while the type of anemia has continues to change (ie IDA-MBA-IDA) the potential behavioral and pathological foundations are similar (see Larsen, 1997). While the functional

etiological aspect of these anemia is discussed here, ultimately, the basal cause lies the in the complex web of biosociocultural interaction.

Differential Diagnosis

Porous lesions affecting the cranial vault and orbital roof while regularly attributed to different forms of anemia, have also been linked to other pathological conditions. Recent work by Walper et al. (2004), found that cribra obitialia was only confirmed in a small percentage of individuals with more than half of the affected individuals having an etiology other than anemia. They indicate that inflammation potential caused by infectious agents may have caused some of the lesions. In addition to infectious disease, metabolic diseases, specifically scurvy and rickets have been linked to porotic hyperostosis and cribra orbitalia. For the most part some of these disorders should be eliminated as a potential differential diagnosis. This primarily is based on the pathophysiology related to IDA, MBA and hemolytic anemia and the effect this process has on marrow and consequently, bone. For example, the porosity observed in clinical and archaeological cases of scurvy, where the cranium is involved, is largely found with marrow hyperplasia. Furthermore, the porosity found is in part related to hemorrhage and new bone growth and not marrow hyperplasia. Here and in other cases where ectocranial porosity is observed a better understanding of the pathological processes involved in the formation of the lesion, will help in avoiding using PH and CO as unilinear terms. As such the terms PH and CO will be restricted for use specifically related to anemia.

In a survey conducted by Walker (1986) he identified a high prevalence, similar to what was found in Maize dependent mainland Native American societies, of morphological skeletal

characteristics (PH/CO), often considered to be indicative of IDA, in a coastal Prehistoric Native American population from the Channel Islands. As noted above, a primarily maize based diet could lead to IDA if an iron supplement is not included in the diet.

4.9 Specific Disease Categories – Dentition

4.9.1 Dental Caries

Dental caries are the result of a progressive demineralization of dental tissues resulting from the acidic byproduct from plaque bacterial fermentation of carbohydrates, within the oral cavity, of which sugars are likely to play the most significant role (Hillson, 1996). More specifically, bacterial species that are most often associated with caries formation are *Streptococcus mutans* and *Lactobacilli acidophilus*. These microbes adhere to dental plaque deposits and produce an acidic (≤5.5 pH) environment resulting from fermentation process of dietary carbohydrates. In addition to carbohydrates, other food types, starches, proteins and fats, have been implicated in the formation of caries. As such, diet as a whole plays a significant role in the overall risk of caries formation. While the pathway leading to the formation of caries is complex with multiple variables, composition of diet would be expected to play a substantial part in the disease process.

Variables Associated with Caries formation

The presence of carious lesion is the result of a process in which the observable lesion (hole) in the dental tissue is likely to be a later phase in the disease process (Hillson 2005). The formation of caries cannot be looked at in the view of a single cause leading to formation of the lesion. From an etiological standpoint, there are numerous variables other than diet that can potentially increase the risk caries formation, which can be separated into intrinsic and extrinsic

phenomenon. Individual genetic variation leading to the production substandard enamel, crown and tooth crown morphology, hormonal levels, lactation and saliva production levels are some examples of intrinsic variables that can lead to increased risk of caries formation (Lukas, 2008; Larsen, 1997). Extrinsic factors such as trauma and food preparation can influence caries rate (Larsen, 1997). While it is clear that other variables, including other food sources, need to be taken into consideration, it is likely that diets high in carbohydrates are a primary factor in caries formation in archaeological populations (Cucina et al., 2011).

Caries - Application to Bioarchaeological Studies

The relatively permanent status of lesion and our understanding of the dietary influence on caries formation, the prevalence of caries within a population have been used to address major shifts in cultural behavior, especially as it relates to diet. For example, shifts in subsistence patterns from hunter and gatherer societies to agricultural societies have overwhelmingly shown a positive correlation, with some exceptions (see Tayles et al., 2000; Eshed et al., 2006) between increase caries prevalence and primary reliance on agricultural subsistence (Lukas, 1992; Larsen, 1997; Turner, 1979). In addition, caries prevalence has been utilized to understand differences in social class, age and sex with in a population. These studies, while the focus is different compared to dietary shift studies, the foundation of the differences has mainly to do with diet and more specifically, access to specific food types.

4.9.2 Enamel Hypoplasias

Enamel hypoplasias (EH), defects of decreased enamel thickness, are a consequence of premature cessation or interruption of enamel matrix secretion during amelogensis (Hillson,

1996). Ameoblasts, the cells responsible for the deposit of newly formed enamel, are some of the most sensitive cells to stress in the human body. This fact makes them more susceptible to physiological stress leading to the malfunction of the processes that they are responsible for carrying out.

Mature enamel lacks the ability to remodel once it is formed, which affectively preserves any defects formed during the deposition of the enamel matrix, thereby creating a permanent record of episodes of physiological stress. With some amount of variation in the timing for completion of enamel formation for permanent teeth, the crowns of the 3rd molars are usually complete with in the 13th year of life thereby ending the period in which hyoplastic defect can be formed.

Enamel formation follows are regular process in which the tips of the cusps are formed first with formation proceeding towards the root. This deposition is highly regulated by genetic and less influenced by environmental factors as compared to other hard tissues such as bone. This standard direction and the general regularity of formation allows for the calculation and correlation of defects with physiological development of the tooth and connection with chronological age, effectively allowing for the calculation of the approximate age at which the period of stress occurred.

Enamel Hypoplasia – Etiology

The etiology of hypoplasia fall into two main categories: Genetic or Hereditary and Acquired. Below is brief explanation of both categories of enamel hypoplasia.

Genetically or hereditary based enamel hypoplasias are categorized under the term Amelogensis Imperfecta (AI). This term represents a group of disorders that affect the deposition and form of terminal enamel but without having a systemic or acute etiology (Wasterlain and Dias, 2009). Similar to trauma bases enamel defects genetically based defects occur infrequently in populations (Larsen, 1997; Hillson, 1996) and in some cases only occurring 1 in 14,000 individuals (Hillson, 1996). It has been found that genetically linked AI can be caused by mutations of the amelogenin gene on the X chromosome or by mutated autosomal chromosomes (Hillson, 2005).

Characteristically, AI affects both the primary and secondary teeth in the same individual (Suckling, 1989, Hillson, 1996) and is likely to affect all teeth. Since the disruption of enamel formation is based on genetics amelogensis cannot happen normally if the individual suffers from AI. In modern cases, it has been shown that all teeth are affected. Archaeologically, there has been only a hand full of cases reported (see Hillson, 1996 and Wasterlain and Dias, 2009). According to Wasterlain and Dias (2009), the general lack of reporting of AI in paleopathology might be the result of incorrect diagnosis. The characteristic lesions associated with AI and the fact that it is likely to encompass the entire dentition (Suckling 1989, Hillson, 1996) makes it easier to exclude during analysis. AI, however, in rare cases can affect individual teeth (Hillson, 1996) making it more difficult to differentiate from systemic or acute based hypoplasic defects.

Morphologically enamel hypoplasias that result from acute trauma are no different than those that form under systemic pathology. In order differentiate between acute and systemic based hypoplastic defects multiple the left and right tooth of the maxilla or mandible need to be

observed. Acute trauma will often affect one tooth in one quadrant of the arcade without affect its antimere. There is, however, a problem that arises in that single teeth or maxillae or mandibles that have either lost teeth anti-mortem or post-mortem antimeres cannot be compared. In this regards, systemic vs acute often cannot be distinguished unless another class of tooth contains a defect that was formed at the same time period as the defect on another tooth of a different class.

Systemic hypoplasias occur during a period of prolonged physiological stress. Earlier studies have be linked to a number of metabolic disorders including Vitamin C and D deficiencies to the formation of enamel hypoplasia (El-Najjar et al., 1978), both of which have more serious changes during early childhood. Kalnins (1951), suggests the possibility that enamel hypoplasias are related to scurvy, noting that some researchers have identified scurvy as a primary cause for enamel defects while other relate them to secondary consequences of chronic vitamin C deficiency. El Najjar et al. (1978) note that in addition to metabolic disease gastrointestinal, genetic disorders, children with congenital allergies, as well as the ingestion of specific classes of drugs (tetracyclines). Clinical studies focusing on the etiology of hypoplasia have linked the deficient secretion of enamel in primary teeth to chronic renal failure (Koch et al., 1999). In addition to the potential causes identified above, poor nutrition, infection, and prolonged high fevers have also been implicated in the formation of EH. It is clear from the literature dating back to the early 20th century that any number of disorders has the potential to adversely affect, the secretion of the enamel matrix, leading to the formation of enamel hypoplasias. Bioarchaeologists likewise refer to enamel hypoplasia as non-specific indicators of stress, linking them to extended periods of systemic or acute trauma.

It should suffice to state that exact etiology is not easily knowable. The fact that these defects are found in individuals with a variety of disorders suggests that the development of hypoplastic defects cannot be summed up to a simple cause and effect chain.

Chapter 5

Paleopathology – Results

5.1 Introduction

The following chapter will discuss the results of the bone and dental pathological analysis for the non-adult sample from the Roman Sirmium Cemetery of St Sineros (Locality 26).One of the primary objectives of this thesis is to identify specific pathological conditions affecting bone and dental material from non-adults and to assess group both group and individual morbidity as they relate to age and culture. The results will presented as separate sub-chapters related specific bone and dental pathological conditions discussed in Chapter 4. Etiological consideration will be presented in chapter 7. Each specific pathology section (i.e Cribra Orbitalia) will first discuss the methods used for analysis followed by the results. The data presented in this chapter will specifically aid the overall interpretation of the Sirmium sample, specifically when the biological and cultural data is combined

Pathology Results – General Bone and Dentition

All bone and dental material complete enough for analysis was assessed for pathology. Slightly less than 70% (71/102) of all individuals from the Sirmium sample exhibited evidence for bone pathology for which the majority (n=50) of the affected were found to be from the CH2 cohort (71.42%). CH1 and ADO comprised approximately 20% (n=14) and 7% (n=5), respectively, of the affected while infant and perinatal cohorts each accounted for 1.4% (n=1) of individuals with evidence of bone pathology. Table 5.1 displays the distribution of bone pathology for all age categories. Comparison between the major age categories found no significant difference in the prevalence of bone pathology.

Table 5.1- Bone Pathology – Age Distribution

Behavioral Group	AGE-CAT	AFF	PRE	% OF N1	% OF N2	% OF N3	% OF N4
	FET	0	6	0.00%		0.00%	0.00%
Weaning	PERI	1	3	33.33%	61.11%	33.33%	0.98%
	NEO	0	2	0.00%		0.00%	0.00%
	INF	1	2	50.00%		50.00%	0.98%
	CH1	14	21	66.67%		79.01%	
Post-Weaning	CH2	50	60	83.33%	76.92%		62.75%
	ADO	5	8	62.50%		62.50%	4.90%
	TOTAL	71	102				69.61%

Key: A-CAT= Age Category; FET=Fetal; PERI=Perinate; NEO=Neonate; INF=Infant; CH1=Child 1; CH2=Child 2; ADO=Adolescent

Of the 18 individuals that were of weaning age 11 (61.1%) exhibited bone pathology while slightly less than 77% (60/78) of the post-weaning age individuals had evidence of bone pathology (see Table 5.1, column 3). The difference between the prevalence of bone pathology for these two groups was found not to be statistically significant (Yates χ^2=1.166; df=1; p=<.2802).

Dental pathology was a similarly high frequency as was observed with bone pathology. Of the 61 individuals with observable dentition 53 (86.88%) had dental pathology. The distribution of dental pathology according to age category can be found in Table 5.2. All age groups (with the exception of INF) displayed a high prevalence for dental pathology. There was no statistical difference between age categories with related to the prevalence of dental pathology.

Table 5.2 – Dental Pathology – Age Distribution

A-CAT	AFF	PRE	% OF N1	% OF N2
INF	0	1	0.00%	0.00%
CH1	7	13	53.85%	
CH2	40	41	97.56%	87.04%
ADO	6	6	100.00%	100.00%
TOTAL	53	61		86.89%

Key: A-CAT= Age Category; FET=Fetal; PERI=Perinate; NEO=Neonate; INF=Infant; CH1=Child 1; CH2=Child 2; ADO=Adolescent

When combined, 45 individuals displayed both dental and bone pathology of which, 40 (88.8%) were children and the remaining 5 were between the age of 15 and 17 years old (11.1%). Within the child cohort, CH1 individuals accounted for 6 of the 40 (15%) children with bone and dental pathology while CH2 represented the remaining 34 affected children (85%).

5.2 Cribra Orbitalia and Porotic Hyperostosis - Results

5.2.1 Cribra Orbitalia Reuslts

Introduction and Methods

All orbital material from all relevant age groups was evaluated for evidence of Cribra Orbitalia (CO). In total, 86 (94.5%) of the 91 orbits were complete enough for assessment with an even distribution between left and right orbits. These 86 orbits represent 48 (96%) of the 50 individuals with orbital regions. Of these 48, 29 (60.41%) were found to have lesions characteristic of Cribra Orbitalia (see Table 5.3). Individuals from the CH1, CH2, and ADO age categories exhibited CO; no neonates or infants presented orbital lesions associated with CO. Of the 86 orbits, 55.81% (n=48) displayed cribra orbital, with the left side accounting for slightly more than 52% of the 48 orbits with CO.

Bilateral lesions were identified in 19 individuals of the 23, or 82.60% that retained both left and right orbits while unilateral CO was identified in 17.39% (4/23) of the remaining individuals with both orbits. The remaining specimens could not be scored for bilaterality of CO due to post-mortem damage or post-mortem loss of one of the orbits. Comparison of the difference between prevalence of bilateral and unilateral lesions was found to be statistically significant (Yates Correction χ^2=17.043; df=1; p=<.0001).

The methods used for the scoring of CO are based on those found in Stuart-Macadam (1985); Jacobi and Danforth (2002), and Buikstra and Ubelaker (1994). Each orbit that was at least 25% complete (anterior ½ of the orbit), was evaluated for abnormal porosity, severity, density of pores, lesion status (healed or active) and diploe expansion. Severity was scored on a scale of 0-4. Score 0 was recorded as not showing any evidence for porosity and score 1 displayed some porosity that but was not considered to be abnormal or pathological. Orbits that were scored as a 2 exhibited porosity that was minimal but was considered to be pathological. Orbits with scores of 3 or 4 both had pores that exhibited coalescing but in the case of score 3, there was no evidence for thickening of the diploe. Expansion of the diploe or evidence of vertically oriented trabecular bone was associated with a score 4. Density was based on the number of pores within affected orbital region. The scoring of this particular characteristic was based on Osteoware Database. The status of affected orbit was evaluated for activity. Lesions were considered to be active if the borders of the pores were clearly defined and sharp while those with smooth edges were considered to be healed. In some cases healed and active lesions were identified on the same orbit. These were recorded as having mixed lesions but for statistical purpose individuals with mixed lesions were considered to have active CO at time of death. Diploe expansion was not readably observable in all individual with CO. Thickening was based on expansion of the inner table of bone outside the norm.

General Age Distribution

Table 5.4 displays the distribution of CO according to age category with in sample population. Evidence for CO was identified in children (CH1 and CH2) and ADO but was not observed in

younger aged individuals from neonate or infant age groups. Of those of weaning age (0-3 years of age), 40% (4/10) were found to have CO lesions, of which all affected individuals were from the CH1 cohort. No statistically significant difference was identified between weaning and post-weaning individuals (Yates Correction χ^2=1.255; df=1; p=.2625). Members from the CH2 cohort showed a higher prevalence (63.64%) of CO compared to children between the ages of 1-5 years for age (see Table 5.3). This difference was, however, found not to be statistically significant (Yates Correction χ^2=.003; df=1; p=.9559). Comparison between the prevalence of affected individuals from the CH and ADO groups found no statistical difference (Fisher's Exact Test: p=1.000).

Table 5.3 – Cribra Orbitalia – Age Distribution

A-CAT	CULTURAL	AFF	PRE	%OF N1	%OF N2	%OF N3	%OF N4	%OF N5
NEONATE	WEANING	0	1	0.00%	40.00%	0.00%	0.00%	0.00%
INFANT	WEANING	0	1	0.00%		0.00%	0.00%	0.00%
CHILD 1	WEANING	4	8	50.00%		61.90%	55.56%	54.17%
	POST-WEAN	1	1	100.00%	65.79%			
CHILD 2	POST-WEAN	21	33	63.64%			63.64%	
ADO	POST-WEAN	3	4	75.00%		75.00%	75.00%	6.25%
TOTAL		29	48					60.42%

N1=compares individual age categories splits CH1; N2=compares weaning and post-weaning; N3=compares all CH to ADO and INF and NEO; N4= compares individual age groups CH1 combined; N5=compares individual groups out of total sample (48); all CH combined

Cribra Orbitalia – General Distribution – Children (1 – 14)

Cribra Orbitalia affected children that ranged in age from 1 to 13.8 years old. Due to post-mortem damage/loss, of the 81 children represented in the skeletal material from Locality 26, only 60 (67.61%) had cranial/skull bones present and of these a total of 42 (79.17%) retained at least one that was at least 25% complete.

Cribra Orbitalia was present in 26 of 42 (61.9%) children between 1-14 years old (see Table 5.3 column N3). Individuals considered to have exhibited CO obtained scores of 2 and above. In addition to those individuals with CO there were 4 children with porosity scores of 1 that were considered not to have CO and were thus removed from further CO analysis. Of the 26 children affected, 5 (19.23%) were from CH1 with the remaining 21 (80.76%) representing individuals between the ages of 6 and 14 years of old.

In all, there were a total of 75 orbits, 37 right orbits and 38 left orbits representing the 26 children. The disparity between the sides is related to post-mortem damage or loss of the orbital roof in a given skeleton. Loss of elements or a region of a bone is a common finding in archaeological skeletal material and even more so, with the more fragile areas of the cranium. Of the 75 orbits evaluated for CO, 45 (60%) were found to show the morphological feature in question. The distribution of affected orbits according to age-category is found in Table 5.4.

Table 5.4 – Lesion Distribution – Orbits

A-CAT	L-ORB-AFF	L-ORB-PRE	%OF N1	%OF N1 COMB	R-ORB-AFF	R-ORB-PRE	%OF N2	%OF N2 COM	COMB (L&R)
INF	0	1	0.00%		0	1	0.00%		0.00%
NEO	0	1	0.00%		0	1	0.00%		0.00%
CH1	4	7	57.14%	59.46%	5	7	71.43%	57.89%	58.67%
CH2	18	30	60.00%		17	31	54.84%		
ADO	2	3	66.67%		2	4	50.00%		57.14%
TOTAL	24	42	57.14%		24	44	54.55%		55.81%

Key: A-CAT= Age Category; NEO=Neonate; INF=Infant; CH1=Child 1; CH2=Child 2; ADO=Adolescent

Children 1-5 Years Old

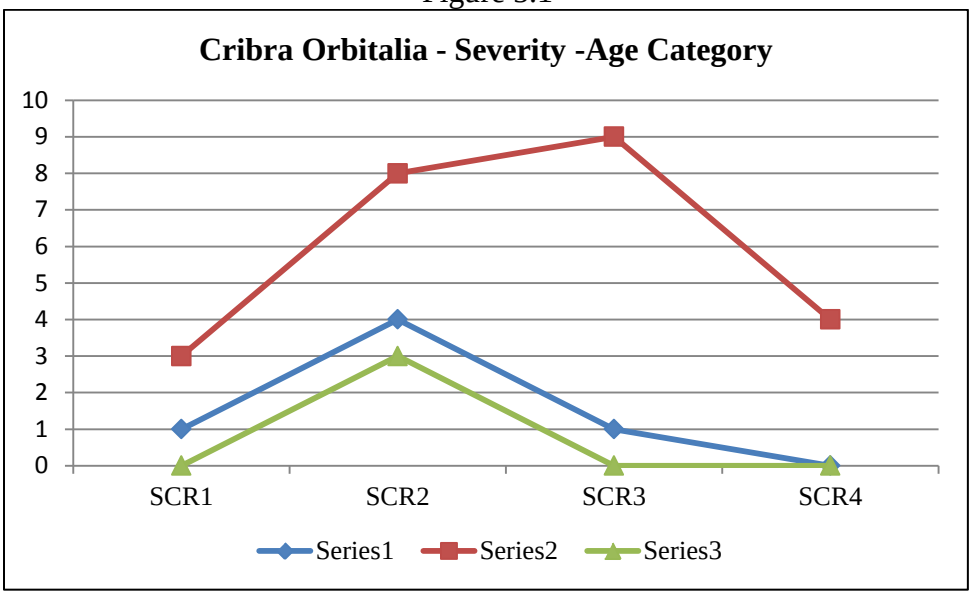
Of the 48 individuals assessed for CO, 9 were from the CH1 cohort. This age group contained five individuals or 55.5% of the CH1 cohort (5/9) that exhibited morphological changes

consistent with CO. In addition to the 5 children affected with CO, one child displayed minimal porosity (SCR 1). Weaning age (pre-weaned) children comprised the majority of individuals (8/9) from this group in addition to accounting for the majority of affected children from CH1 (see Table 5.4). Of the 14 orbits representing the 9 children from CH1, 9 individual orbits showed CO (64.28%). Bilaterality of orbits was observed in all affected children with both orbits (4/4) present while the remaining affected child could not be assessed for bilateral lesions due post-mortem damage to the orbit.

Cribra Orbitalia Severity

Figure 5.1 displays the distribution for CO severity according to general age category. Of the five children from CH1, four (80%) were found to show true porosity with pores up to 1mm in diameter (SCR2), while the remaining child (20%) displayed moderately severe CO (SCR3). No individuals from this group exhibited severe CO (SCR 4). Among the weaning aged children (n=4), one individual showed moderate CO (SCR3), with the remaining three and the one post-weaning aged child showing minimal severity CO (SCR2).

Figure 5.1

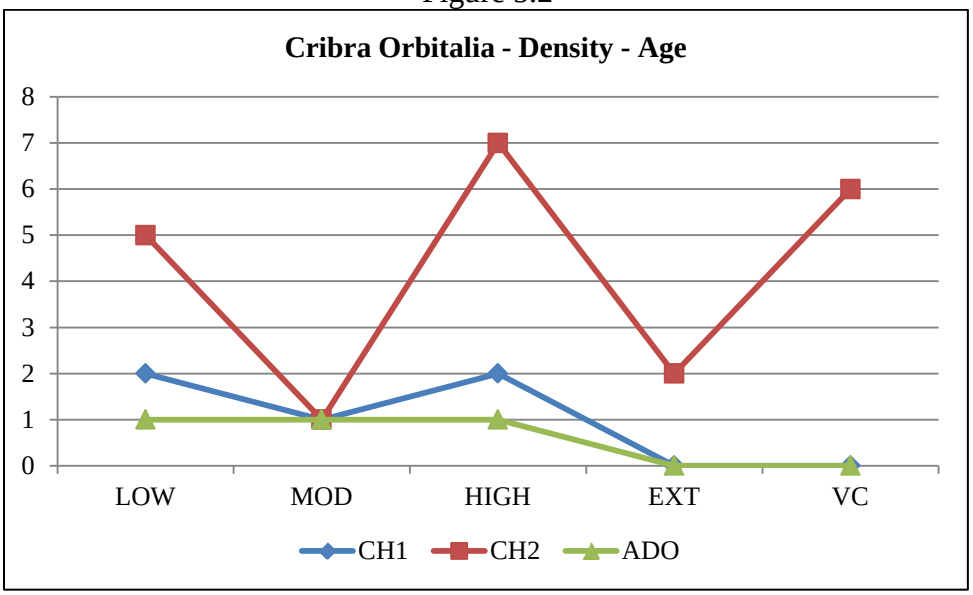


Key: CH1 (Series 1)=Child 1 (1-5); CH2 (Series 2)= Child 2 (6-14); ADO (Series 3)=Adolescent (15-17)

Cribra Orbitalia Density

As depicted in (Figure 5.2), density of pores affecting the anterior ½ of the orbital surface were found to span from Low or less than 15 pores per area to a high density or between 25 and 50 pores per affected area. Of the 5 children with CO in this age group 2 individuals (40%) had a low density of pores, 1 child (10%) had moderate density of pores affecting the region and 2 children (20%) had a high density of pores. No porosity affecting this age group displayed Extreme or Very Coalesced density of pores. Two of the four children that retained both orbits exhibited non-symmetrical pore density. Both individuals had one orbit that showed a moderate density with one exhibiting high and one low density for the opposite orbit. In both cases the more elevated density score was depicted in the overall statistics.

Figure 5.2



Key: CH1=Child 1 (1-5); CH2= Child 2 (6-14); ADO=Adolescent (15-17)

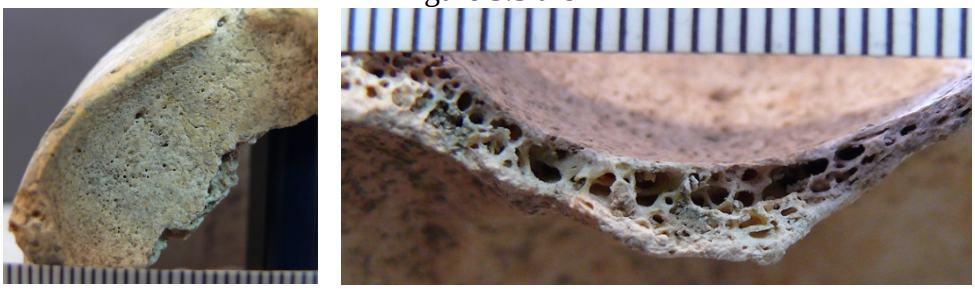
Cribra Orbitalia Diploe Expansion

The five children between 1 and 5 years of age that were identified as having cribra orbitalia, were represented by a total of nine orbital surfaces (4 left and 5 right). Evaluation of the orbital region for evidence of diploe expansion was possible for all children within this age range for at least one orbit. For three of the five children, however, it was not possible for one of the orbits to be assessed due to orbital incompleteness or post-mortem damage (PMD). Based on ectocranial characteristics it was observed that 3 of the 5 (60%) children showed some evidence for possible dipole expansion (PDE). One of these children (BCL268N-1) did not exhibit bilateral symmetry as surface features that would suggest diploe expansion were not observable.

Only one of the 5 children between the ages of 1 and 5 years exhibited diploe expansion. The left and right orbits of this child (BCL2612ASW-QUAD-1) did not show any signs on the ectocranial surface that would suggest diploe expansion (large coalescing pores and or extension of the trabecular bone from the inner table of the orbits). The left orbit of this individual suffered

PMD/loss to the posterior ½ of the roof, resulting in an unobstructed view and in the assessment of the diploticc region. Based on the criteria discussed in Stuart-Macadam (1987) it was determined that there was in fact abnormal thickening of the diploe (see Figure 5.3a-b). While the right orbit was not observable due to completeness, a thin section of the orbital roof (NYU ID#4) did provide clear evidence of thickening of the inner table of bone.

Figure 5.3 a-b



a. The external surface of the left orbit exhibit minimal expression of CO; b. Left orbit of same individual displaying abnormal thickening of the inner table of bone suggestion hypoplasia

Cribra Orbitalia Status

Healed CO was identified in two of the 5 affected CH1 individuals, while active lesions were found in the remaining 3 children. With the exception of one child that exhibited healed and active lesions on opposite orbits, and one child that retained a single orbit, all other children show bilateral symmetry of lesion status, when both orbits were present. Individuals of weaning age, showing CO, displayed both active and healed lesions. The single child of post-weaning age (>3 years old) with CO, exhibited healed porosity only.

Cribra Orbitalia Location

All affected children in the 1-5 year old age range had porotic lesions restricted to the anterior ½ section of the orbital roof. Within this section, 1 of the 5 children, had the porosity affecting the middle 1/3, 1 exhibited lesions restricted to the medial ½, 1 showed porosity only distributed on the lateral ½ of roof, and 1 displayed a pores covering the entire anterior section. The last child

exhibited lesions on the lateral ½ of the left orbital roof while the right orbit anterior ½ was complete covered. There were no cases of porosity extending to the posterior ½ of the orbital roof with any significance.

Children 6-14 Years Old

Cribra Orbitalia was observed in 21 (63.63%) of the 33 children from CH2 (see Table 5.3) and accounted for approximately 44% of all individuals with CO. Affected CH2 children ranged in age between 6 and 13.8 years of age. Of the 61 orbits present for analysis, 35 (57.37%) displayed CO, with the left orbit showing a slightly higher prevalence compared to the right (see table 5.4). The difference was found to not be statistically significant (Yates Correction χ^2=.022; df=1; p=.8819).

Cribra Orbitalia Severity

Figure 5.1 diagrams the distribution of orbital lesion severity for children between 6 and 14 years of age. Unlike individuals from CH1, children from CH2 displayed a full range of CO severity, thus exhibiting a more advanced stages of Cribra Orbitalia. Of the 21 that individuals that exhibited cribra orbitalia there were 8 (38.95%) children that obtained minimal (SCR 2) scores for porosity, 9 children or 42.85% showed evidence of coalescing of pores (SCR 3) and 4 (19.04%) individuals were found to have lesions that showed evidence of coalescing pores with thickening and or extension of the trabecular bone (SCR 4).

Bilateral symmetry in regards to severity was observed in 12 of the 18 (66.66%) children with both orbits present, with 3 of 18 (16.66%) showing different scores for the left and right orbits.

Three children could not be assessed for bilateral lesions due post-mortem loss/damage to the orbital surface. Two of the three children with mixed orbital status contained one orbit with extreme CO and one with moderate CO, while last child displayed minimal severity (SCR2) on the left orbital and non-pathological porosity on the right (SCR1). For statistical purposes these children were grouped under the more extreme severity score, SCR4 and SCR2, respectively. Lastly, three children displayed porous lesions of minimal severity (non-pathological).

Cribra Orbitalia Density

Figure 5.2 displays the distribution for porosity density for CH2. The scoring of orbital density was found to span the entire range, from Low to Very Coalesced (VC) which differs from the density range found in both CH1 (see above) and ADO (see below). Observation of the 35 affected orbital regions indicated that individuals with High and VC density represented the largest groups, with 6 (28.57%) and 7 (33.33%) members, respectively. Low density porosity showed slight lower prevalence (23.80%) compared to High density. Moderate and Extreme density scores comprised the lowest prevalence of affected CH2 making up 4.76% and 9.52%, respectively, of affected children from this cohort.

Symmetrical density scores were found in 8 (53.3%) of the 15 children with both orbits present and observable for density scoring. The remaining seven children with both orbits exhibited non-symmetrical lesion density and were allocated to the more extreme density score for statistical purposes. Bilaterality in relationship to density of pores could not be assessed for 6 children from CH2 due to post-mortem loss or damage to the orbital surface.

Cribra Orbitalia Status

Twelve of the 16 (70.58%) children with both orbits complete enough for pathology assessment, exhibited orbital lesions that were bilaterally symmetrical in regards to activity. Bilateral mixed lesions (active and healed) were found on 3 of the 16 children with both orbits (17.64%). Individuals with symmetrical healed CO constituted a total of 8 children or 50.00% of CH2 members with both orbits. Unilateral mixed orbital lesions included those individuals that exhibited bilateral non-symmetry of lesion status. The 5 children, 31.25% of the 16 children with both orbits present, with non-symmetrical lesion status were found to have a mixture of active/mixed and healed/mixed CO lesions.

Based on the assessment of all observable orbital surfaces for CH2, there were a total of 14 (66.6%) individuals that did not have active lesions and 7 (33.3%) individuals with some evidence activity. The difference was found to be not quite statistically significant (Yates Correction χ^2=3.429; df=1; p=.0641).

Cribra Orbitalia Diploe Expansion

Evidence for the expansion of the inner table of bone or diploe was assessed for individuals with CO. Of the 21 affected CH2 members, observation of diploe expansion was potentially identified in 15 individuals (71.42%), with the remaining 6 children having the inner table of bone not observable and or the outer surface not displaying characteristics often associated with DE.

In most instances, confirmed diploe expansion was not identifiable. From the 6-14 year old cohort there were a total of 38 individual orbits, of which 37 exhibited CO and one showed no evidence for pathology. Of the 37 individual orbits, confirmed diploe expansion was found to

affect 6 individual orbits. Alternately, no diploe expansion was identified on a single orbit. Combined PDE and NOBS (Not Observable) for the inner table of bone comprised the majority of DE findings for individual orbits (30/37) for this age group.

Definite diploe expansion was recognized in 3 (16.67%) individuals all of which contained the left and right orbits. In each of these children bilateral symmetry was present. Confirmation of the expansion or the outgrowth of trabecular bone was made using CT-imaging (BCINV10M-8) and macroscopic observation (all) of orbital cross sections that were the result of PMD. There were no cases in which there was no evidence of enlargement of the inner table of bone for these specific individuals.

Adolescents

Adolescents accounted for 8.00% (n=4) of the total number of individuals with at least one complete orbit (see Table 5.3), of which 3 (75.00%) exhibited morphological characteristics consistent with CO. In total, there were 8 orbits present, of which 7 were complete enough for pathology assessment. Of these 7, 4 (57.14%) were pathological. All adolescents with CO exhibited minimal severity scores (see Figure 5.1) in addition to all lesions showing healed surface morphology. Bilateral symmetry was identified in the single individual that retained both orbits. The remaining adolescents with CO could not be evaluated due to the loss or damage to the opposite orbit. Diploe expansion could not be assessed for any of the affected adolescents. Of the 3 affected, one individual exhibited low density porosity, one individual showed moderate density porosity, and one individual displayed high density porosity (see Figure 5.2).

5.2.2 Porotic Hyperostosis – Results

Introduction and Methods

The vault bones, frontal, left and right parietal and occipital bones were evaluated for the presence of porotic hyperostosis (PH) for all individuals that satisfied the parameters discussed previously. The scoring system used for PH evaluation of cranial bones followed the parameters discussed previously for cribra orbitalia (see above). Slightly more than 94 % (170/179) of the targeted vault bones were complete enough for porotic hyperostosis evaluation. Together, these bones comprised 34.69% (170/490) of the total skull bones that were complete enough for pathological assessment. Of the 170 bones, evidence for PH was identified in 16 of the bones, (9.41%) all of which were represented by parietal and occipital bones. Table 5.5 displays the distribution of affected bones according to bone type.

Table 5.5 – Porotic Hyperostosis – Cranial Bone Distribution

BONE	SIDE	AFF	PRE	%OF N1	%OF N1-COMB	%OF N2
FRONTAL		0	50	0.00%		0.00%
PARIETAL	LEFT	7	42	16.67%	16.25%	
	RIGHT	6	38	15.79%		7.65%
OCCIPITAL		3	40	7.50%		1.76%
TOTAL		16	170			9.41%

N1=% of affected specific bone out of total for that particular bone; N1 COMB=% of affected combined paired bones (parietals); N2=% of affected vault bone type out of total number of vault bone present (n=170)

General Age Distribution – PH and Result for all Age Groups

The distribution of affected individuals according to age category is displayed in Table 5.6. No significant difference was identified in pair-wise comparisons between CH1 and CH2 (χ^2=.142 df=1, p=.7064). Similarly, no statistical difference was found between the prevalence of affected children (CH1 and CH2) when compared to adolescents (Fisher's Exact Test: p=1.000). Further comparison between weaning and post-weaning individuals (age set at 3 years-see chapter 6)

showed further evidence for a lack of significance between affected and unaffected individuals (χ^2=.1523 df=1, p=.2172).

Table 5.6 – Porotic Hyperostosis – Age Distribution

A-CAT	CULTURAL	AFF	PRE	%OF N1	%OF N1 COMB	%OF N2	%OF N3	%OF N3 COMB
NEONATE	WEANING	0	1	0.00%	0.00%	0.00%	0.00%	0.00%
INFANT	WEANING	0	1	0.00%	0.00%	0.00%	0.00%	0.00%
CHILD 1	WEANING	0	9	0.00%	9.09%	17.39%	0.00%	15.09%
	POST-WEAN	1	2	50.00%			1.89%	
CHILD 2	POST-WEAN	7	35	20.00%	20.00%		13.21%	
ADO	POST-WEAN	1	5	20.00%	20.00%	20.00%	1.89%	1.89%
TOTALS		9	53					16.98%

KEY: N1=% of affected within specific age/cultural category out of total present from specific age/cultural category; N2=% of affected combined for CH1; N2=% of affected complete age category (all Children); N3=% of affected individual age/cultural category out of total vault bone individuals assessed (n=53); N3 COMB=% of affected for combined age category out of total number of vault bones present.

Distribution of PH – Individual Vault Elements

Of the 3 vault bones assessed, the parietal was affected most frequently with 13 of the 80 (16.25%) bones showing morphological characteristics of PH, followed by the occipital with 7.5% of the evaluated bones being affected. None of the 50 frontal bones exhibited changes associated with PH. Comparisons between the parietals (left and right) and the occipital showed no evidence of statistical significance (Yates Correction χ^2=.1091 df=1, p=.2963).

Porotic Hyperostosis - Lesion Status

Of the 16 vault bones with morphological changes associated with PH, 12 (75%) displayed healed lesions, 2 (12.5%) had mixed status lesions and 2 (12.5%) exhibited no external porosity. The later, (BCL2612A-SW-QUAD-1) showed hyperostosis of the inner table of bone or diploe (see below). Mixed (active and healed) lesions were only found on the left and right parietal of a single individual.

Porotic Hyperostosis - Lesion Severity

The majority of the bones with PH lesions were scored as moderate (SCR 2), with pores between pin-prick size and approximately 1mm in diameter. Bones with severity score of 2 accounted for 75% of affected vault bones (12/16). Evidence for PH with pores showing coalescing, was identified on 2 of 16 bones (12.5%). The remaining two bones did not exhibit external characteristics associated with PH but as noted above, exhibited clear evidence for abnormal expansion of the inner table of bone. Of the 9 individual with PH, seven (77.7%) displayed moderate severity scores (SCR2) while only one (1.11%) exhibited score 3 severity and the remaining specimen did not exhibit external porosity.

Porotic Hyperostosis - Density

High density of pores was found to affect 9 of the 16 (56.25%) bones with moderate pore present on 31.25% of vault bones. The two remaining bones did not exhibit external porosity. The density of the pores was not necessarily related to the severity of the lesion as it was found that in some cases high density pore distribution was associated with severity scores of 2. It was found, however, that low density porosity was not present in individual with severity scores of 2-3 and only with individuals with severity scores of 1, which are not considered to be the result of PH. Furthermore, moderate density was not present in the two bones with severity scores of 3.

Porotic Hyperostosis - Diploe Expansion

Of the 16 bones with evidence for PH, only 2 (12.5%) bones exhibited clear hyperostosis of the inner table of bone. These bones from the same individual did not exhibit the normal external characteristics that are regularly observed in PH (see discussion for more detail). Six (37.5%)

bones did not allow for the observation of the inner table of bone, while 7 (43.75%) displayed external characteristics suggestive of possible diploe expansion (bony struts within the pores) but could not be confirmed, and one individual with porotic lesions did not show evidence for diploe expansion.

5.2.3 Cribra Orbitalia and Porotic Hyperostosis - Combined Results

Table 5.7 displays the combined results for CO and PH. Lesions associated with PH and CO were present in 31 individuals that retained both orbital and vault elements complete enough for assessment. Of these 31, 23 (74.19%) were affected with only orbital lesions while, 2 (3.45%) exhibited characteristics associated with PH and not CO. The remaining 6 (19.35%), all of which were of post-weaning age, individuals were found to exhibit pathomorphological characteristics of both CO and PH. The difference between those with CO or PH lesions and those with both types was found to be statistically significant (Yates Correction χ^2=20.903 df=1, p=<.0001).

Table 5.7 –Combined CO and PH – Age Distribution

A-CAT	CO	PH	CO-ONLY	PH-ONLY	CO+PH	% OF N	% OF N COMBINED
CHID 1	5	1	4	0	1	20.00%	16.13%
CHILD 2	21	6	17	2	4	19.05%	
ADOLESCENT	3	1	2	0	1	33.33%	3.23%
TOTAL	29	8	23	2	6		19.35%

Of the 6 showing combined lesions, 1 display active CO and PH lesions. There does not seem to be a relationship between individuals with more severe lesions (SCR >2) associated with CO and severity scores for PH in the same individual. Of the 4 individuals with scores of 3-4 for CO, all but one had a PH score of 2. Similarly, diploe expansion of the orbital roof was identified in 4 of the 6 individuals with both CO and PH with only one of the four showing diploe expansion affecting the vault and the orbits.

5.3 Abnormal Bone Growth – Periostitis –Results

5.3.1 Abnormal Bone Growth - Skull

Introduction and Methods

This section details the results from the evaluation of ABG affecting the skull of individuals from the Sirmium sample. They are presented according to specific bone and or region as they relate to age groups. Of the 516 skull bones present, 490 (94.96%), representing 68 of the 102 individuals (66.66%), were complete enough to be evaluated for pathology (ABG). Table 5.9 displays the distribution of ABG affecting the individual elements of the skull. The sphenoid accounted for the majority of affected cranial material with a prevalence of approximately 29% followed by the ABG the affecting the maxilla (20%). Abnormal bone growth was found in active and healed form.

All skull elements were assessed for evidence of infection. On those bones that retained at least 25% of the surface were included is this analysis with the exception of the basin region and the greater wing of the sphenoid and the sinus cavities of the maxilla and sphenoid which followed a regional protocol for completeness. The basin region of the sphenoid, containing the foramen ovale and rotundum was scored if it was present irrespective of the completeness of the entire sphenoid, which was the same protocol used for the sinus cavities of the maxilla, sphenoid and the greater wing of the sphenoid. Each surface (external and internal) was observed using the unaided eye and then again using low power magnification and scored for the presence of ABG with regards to location and activity.

General Distribution of ABG – Age Categories

Table 5.8, displays the distribution of individuals with abnormal bone growth affecting at least one skull element according to age category. Of the 68 individuals with skull material present, 28 (41.17%) exhibited some form of ABG affecting at least one skull element. No infants or neonates with skull material exhibited abnormal bone growth. Of the 14 children ages between 1 and 5 (CH1) years old, approximately 43% (n=6) were found to have deposits of abnormal bone growth affecting the skull. All of the individuals showing ABG in the CH1 cohort were of weaning age (≤ 3years of age). Accounting for more than 65% of the total sample, individuals from the CH2 sub-sample displayed a similar frequency of affected individuals when compared to CH1 individuals. The difference between these two groups was found not to be significant (Yates Correction: χ^2=.002, P=.9672, df=1). Two of the six adolescents (33.3%) that retained skull material showed abnormal changes indicative of abnormal bone deposits.

Table 5.8- ABG – Age Distribution

	ABG - SKULL - AGE DISTRIBUTION					
		AFF	PRE	%OF N	%OF N COMB	%OF N
NEONATE		0	1	0.00%		0.00%
INFANT		0	1	0.00%		0.00%
CHILD 1	WEANING	6	10	60.00%	42.86%	8.82%
	POST-WEANING	0	4	0.00%		
CHILD 2		20	46	43.48%		29.41%
ADOLESCENT		2	6	33.33%		2.94%

KEY: AFF:Affected; PRE=Present

Distribution of ABG – Individual Bone Elements

Frontal Bone

Of the 52 frontal bones assessed for evidence of ABG, five (9.62%) were shown to display this pathology (see Table 5.9). All of the individuals affected fell into the general age category of children with three representing the CH1 and the remaining 2 were between the age of 6 and 14 (CH2). All five of the individuals, were affected on the endocranial surface with one of the five

showing ABG both on the internal and external surface of the bone. Regions of ABG on the endodcranial surface were restricted to the anterior most quadrants (Q1 and Q2) and orbital regions for all 5 individuals, while the orbital surface was the only area affected on the external surface. Active lesions accounted for 60% (n=3) of the endocranial ABG with healed bone growth representing the remaining 40% (n=2). The single area of ABG affecting the external surface was healed at the time of death. There were no insistences in which a mixture of active and healed ABG was identified on the endocranial or ectocranial surface.

Table 5.9 – ABG – Distribution of Affected Skull Elements

ABG - SKULL - INDIVIDUAL BONE FREQUENCY - ECTO AND ENDOCRANIAL RESULTS						
BONE	SIDE	AFF	PRE	%OF N	%OF N COMB L&R	%OF N (ALL CRANIAL)
FRONTAL		5	52	9.62%	9.62%	1.02%
PARIETAL	LEFT	3	42	7.14%		1.02%
	RIGHT	3	38	7.89%	7.5%	
OCCIPITAL		6	40	15.00%	15.00%	1.22%
TEMPORAL	LEFT	5	34	14.71%		2.04%
	RIGHT	5	33	15.15%	14.93%	
SPHENOID		12	41	29.27%	29.27%	2.45%
MAXILLA		10	50	20.00%	20.00%	2.04%
MANDIBLE		7	48	14.58%	14.58%	1.43%
ZYGOMATIC	LEFT	0	25	0.00%		0.00%
	RIGHT	0	31	0.00%	0.00%	
NASAL	LEFT	0	7	0.00%		0.00%
	RIGHT	0	7	0.00%	0.00%	
PALATINE	LEFT	0	13	0.00%		0.00%
	RIGHT	0	13	0.00%	0.00%	
INCUS	LEFT	0	1	0.00%		0.00%
	RIGHT	0	8	0.00%	0.00%	
STAPES	LEFT	0	2	0.00%		0.00%
	RIGHT	0	2	0.00%	0.00%	
MALEUS	LEFT	0	2	0.00%		0.00%
	RIGHT	0	1	0.00%	0.00%	

KEY: AFF: Affected; PRE=Present

Parietal Bone

Six parietals (7.5%), representing 4 individuals, of the 80 parietals assessed (see Table 5.9), had ABG. Of these 6 parietals, representing 4 individuals, had ABG on the endocranial surface and one parietal, (MNI=1) displayed a single button tumor on the external surface. The distribution of affected individuals according to age category found that 3 of the 4 children were between 6 and 14 years old, on child was from the CH1 (1-5 year old) cohort and one individual was of adolescent age. The button tumor was indemnified on the left parietal of the adolescent.

Bilateral ABG on the endocranial surface was only identified in one individual, with the remaining three individuals only showing bone growth on one of the two parietals present from their respective skulls. Active lesions were identified on one of the five parietals while mixed lesions and healed lesion were found equally on the remaining 4 parietals. The single child displaying bilateral ABG had one parietal with active ABG and one parietal with mixed lesions. With the exception of Q1, all other quadrants (Q2-Q4) were affected.

Occipital Bone

Of the 490 skull bones complete enough for evaluation, slightly more than 1.2% of occipital bones were found to be affected (see Table 5.9). Fifteen percent (n=6) of the occipitals evaluated displayed abnormal bone growth (see Table 5.9), all of which were affected on the endocranial surface. Of these 6 occipitals, representing 6 individuals, 4 were from members of the CH2 cohort and 2 were from the CH1 cohort. When assessed for all affected children, it was found that all quadrants (Q1-Q4) had been affected. There was no evidence for individuals with purely

active lesions. Mixed ABG was found on the internal surface of 4 (66.6%) occipitals while the remaining 2 (33.3%) children exclusively showed healed deposits of ABG.

Temporal Bone

Temporal bones were affected at frequency of approximately 2% of the all skull material assessed. Abnormal bone growth was identified on the endocranial surface of 10 (14.93%) of the 67 temporal bones (see Table 5.9), representing 6 individuals. No ABG was found on the external surface. All 5 of the 6 of the individuals with temporal bone ABG were children from CH2 age category and the remaining individual was between the age of 1 and 5 (CH1 cohort).

Four of the five children with both the left and right temporal bones present, exhibited bilaterality of endocranial abnormal bone growth with only one child showing unilateral deposits of ABG. One child retained only one temporal that was complete enough for pathology evaluation. In all cases of ABG for the temporal bone, lesions were found to affect the anterior-inferior region of the squama portion of the temporal often with multiple independent patches of new bone within the normal depressions of the endocranial surface.

Ninety percent (n=9) of the individual temporal bones displayed some evidence for lesions that were active (ACT and MIX) at the time of death while only one child exhibited healed ABG. Of the 4 children with ABG affecting the left and right temporal bones, three displayed bilateral active bone deposits and one was found to have active and healed ABG. One of the children (bilateral assessment not possible) showed mixed (active and healed) deposits of ABG.

Sphenoid Bone

All 41 of the sphenoid bones present, representing 41 individuals, were complete enough to be evaluated for abnormal bone growth. Of these 41, 12 (29.27%) exhibited abnormal bone growth (see Table 5.9) and were distributed between CH1 and CH2 age categories. The majority of affected children were between 6 and 14 (n=10) while the remaining 16.6% were from the CH1 age cohort. Abnormal bone growth was found to affect 3 general regions of the endocranial surface; 1. The basin region, as defined by area associated with the Foramen Rotundum, Ovale and Spinosum; 2. Sphenoidal Sinus; and the Superior Body. The distribution of ABG affecting the endocranial surface affected multiple regions in two (both CH2) of the four children that retained both the Greater Wing and the Sinus cavity. The remaining 6 samples were either missing one of the two areas or the area was not observable (i.e closed sinus cavity).

Sphenoid - Greater Wing – Basin Region

Of the 59 greater wings present and complete enough for assessment, 12 (20.33%) individuals wings, representing 9 individuals, displayed ABG in the form of porous woven plaques of bone on the endocranial surface in the region associated with the F-ROT and F-OVA (see Figure 5.3). The ABG found in area was restricted to the endocranial surface and did not extend (with direct connection) to the external surface. The foramen rotundum and oval did not display ABG within the canal leading to the external surface.

Figure 5.4

Abnormal bone growth on the endocranial surface of the greater wing of the sphenoid associated with the foramen rotundum and ovale.

The coverage of ABG per individual showed slightly more individuals with having a unilateral (n=4) rather than a bilateral (n=3) distribution when both the left and right sides were present. The remaining two children either were missing the opposite GW post-mortem or it was damaged and could not be evaluated. Active lesions were found in 6 of the 9 children with 2 of the 6 only showing ABG that was still active at the time of death and the remaining 4 children showing a mixture of healed (or healing) and active lesion. Only children from CH1 showed only active-type deposits.

Table 5.10 – Sphenoid – ABG – Regional Distribution

	REGION	AFF	PRE	%OF N	%OF N COMBINED
SPH-GW	LEFT-GREATER WING	6	30	20.00%	20.34%
	RIGHT-GREATER WING	6	29	20.69%	
	SINUS	4	10	40.00%	
	OTHER(BODY)	1	14	7.14%	

Key: AFF=Affected; PRE=Present

Sphenoid - Sinus Cavity/Body

The sphenoidal sinus located along the median line of the basal cranium was present 14 of the 41 (34.14%) sphenoid bones. Complete closure of the sinus region did not allow for pathology examination in 4 of the 14 (28.57%) samples. Of the remaining 10 sinus regions 40% (n=4) displayed evidence for abnormal bone growth (see Table 5.10). Three of the four affected

sphenoidal sinuses displayed active deposits of porous woven bone (see Figure 5.5) with varying degrees of coverage and thickness. The remaining individual, showed no evidence for active lesions suggesting that the ABG had healed prior to death. The superior external surface of the body of the sphenoid (located between the left and right lesser wings) showed ABG in one individual of the 14 with this particular region present and observable. The bone growth was healed. The full extent could not be distinguished due to PMD to the surrounding features (i.e. lesser wings, sinus, etc…).

Figure 5.5 – Sphenoid Sinus Cavity

Abnormal bone growth situated on the internal surface of the sphenoidal sinus.

Maxilla

Abnormal bone growth was identified on 20% (10/50) of the maxillae complete enough for evaluation. Affected individuals ranged in age from 2.13 to 15 years of old. Children between the ages of 6 and 13 accounted for the majority of affected individuals (8/10) with CH1 and ADO cohorts being represented by one individual each. One of the ten individuals showed ABG on the external anterior surface. All of the remaining affected individuals were found to have ABG within the left or right sinus cavity. This accounted for 20.45% of the individuals that retained at least one observable sinus cavity (n=44). Six of the 50 maxillae could not be assessed due to

PMD or closure of the sinus. Bilateral deposits of ABG within the sinus cavities were observed in 3 of the 8 specimen with both sinuses present while one individual retained the right sinus only. Active lesions were found in 6 of the 10 individuals, all of which had deposits located within sinus cavities. All three of the non-adults with bilateral sinus cavity ABG displayed active new bone affected both cavities. The morphological characteristics varied with some individuals exhibiting porous woven bone and some with spicule bone formation.

Table 5.11 – Maxilla – ABG – Regional Distribution

	REGION	AFF	PRE	%OF N	%OF N COMBINED
MAXILLA	LEFT-SINUS	8	44	18.18%	14.29%
	RIGHT-SINUS	4	40	10.00%	
	EXTERNAL	1	50	2.00%	
	TOTAL	10	50	20.00%	

KEY: AFF: Affected; PRE=Present

Mandible

Mandibles accounted for 9.79% (48/490) of the total skull material evaluated for evidence of abnormal bone growth. Individuals retaining a significant portion of the mandible ranged in age from neonate to adolescent with the majority represented by children from the CH2 cohort (n=32).Of these 48, 9 or 18.75% showed ABG on the lingual or labial surface of the mandible (see Table 5.12). The internal surface of the ramus was affected most frequently (77.7%) with external surface of the mandible showing ABG approximately 33% (n=2) of the time. One child displayed ABG exclusively on external surface of the mandible while the majority of affected children were found to have ABG on the lingual surface. One of the 2 children with ABG on the external surface had ABG on the lingual surface.

Table 5.12 – Mandible – ABG – Regional Distribution

	REGION	AFF	PRE	%OF N
MANDIBLE	LEFT-RAMUS	5	7	71.43%
	RIGHT-RAMUS	3	9	33.33%
	TOTAL	9	48	18.75%

KEY: AFF:Affected; PRE=Present

The distribution of ABG on the lingual surface was restricted to 2 specific regions; 1. The mandibular notch (Q1-ENDO) and 2. The region associated with the myliohyoid grove mandibular foramen (Q2-ENDO). Of the 8 children with ABG on the internal surface, seven had deposits of bone affecting the notch region and five of the displayed ABG affecting Q2-ENDO. Four of the five with ABG at Q2-ENDO also were found to have ABG affecting Q1-ENDO (no direct continuation was identified between these two areas). Slightly less than 78% (n=7) of those affected retained the left and right side of the mandible. Of these seven, two (28.57%) displayed bilateral deposits of ABG, with the left side being affecting slightly more than the right in the remaining five children.

Individuals with Multiple Bones Affected

Sixteen of the twenty-eight individuals (67.14%) with evidence for ABG were only affected on a single skull bone while the remaining sample (n=12) exhibited ABG on two or more bones (see Table 5.13). There was no statistical significance between the average age of individuals with one skull bone affected or with multiple affected bones. (unpaired t-test: P=.8219; CI=95%; df=26).

Two of the twelve individuals (16.6%) with multiple skull elements affected were from CH1 with the remaining 10 individuals falling between the age of 6 and 14 (CH2). Both children with from CH1 were of weaning age.

Table 5.13 – ABG – Individuals with Multiple Skull Affected

BCINV	AGE	A-CAT	AFF	#OF BONES	%OF N
8N-1	1	CH1	2	9	22.22%
10C-1	2.67	CH1	7	15	46.67%
11EF-EXT-1	6	CH2	4	14	28.57%
4J-1	6	CH2	4	7	57.14%
12ANW-QUAD-2	7.38	CH2	6	8	75.00%
10F-2	7.64	CH2	4	10	40.00%
9N-EXT-7	8	CH2	2	10	20.00%
11J-1	9.45	CH2	2	17	11.76%
12ASW-QUAD-2	11.31	CH2	3	11	27.27%
5K-1	12.46	CH2	4	11	36.36%
7G-4	13.5	CH2	2	11	18.18%
8F-1	13.8	CH2	2	12	16.67%

The majority of individuals with multiple element displaying ABG were shown to have two bones affected (5/12) followed by individuals with four elements affected (4/12), and then by individuals with 3, 6, 7 bones affected each of which were associated with a single individual.

5.3.2 Abnormal Bone Growth – Long Bones

Introduction and Methods

There are a total of 72 or 70.588% of all individuals (n=102) that retained long bones (non-MTs and MCs) of which 71 (BCL267F-2) retained bones that were complete enough for analysis of ABG. Of the 71 individuals with long bones observable, 20 individuals (28.16%) displayed evidence for ABG. In total 379 long bones were assessed of which 369 (97.36%) were complete enough for analysis. The distribution according to bone and side is found in table 5.15. Of the 369 long bones observable 56 (15.17%) displayed ABG. From an individual bone standpoint 15.17% (56/369) of all long bone were affected where the majority of skeletal elements were found to be from individuals that are members of the CH2 age category.

Prior to assessing the material for evidence of pathology, each bone was scored for overall completeness in addition to surface completeness and preservation. Only material that was greater than 25% complete (shaft and or proximal/distal end) was considered. Following this primary assessment each individual surface (anterior, medial, lateral and posterior) was scored according to their individual preservation. Surfaces with scores below 25% (SCR 4) complete were not considered complete enough for pathology evaluation. More specifically, in regards to the scoring of periostitis, only bones that retained at greater than 25% (SCR 1-3) of the shaft were used.

The external surfaces of each bone was assess for the presence abnormal bone growth (ABG) and then described in terms of coverage and whether or not there was continuation of ABG between the surfaces of shaft. In addition, each segment of ABG was scored for 'Activity'. Lesions were designated as being 'Active', 'Mixed' or 'Healed'. Periosteal bone thickness was recorded only in circumstances were previous PMD exposed cross sections or where it was possible to make approximate measurements on the surface of the ABG.

Distribution of ABG – Age Category

Table 5.14 displays the distribution of individuals with ABG according to Age Category. Members of the CH2 cohort comprise the largest number of affected individual accounting for 75% of all affected people. When compared to the frequency of affected individuals in other age categories, the differences were found to be statistically significant when CH1 1 and CH2 2 cohorts were compared (Fisher's Exact Test: P=.0238) but not between CH2 2 and ADO

(Fisher's Exact Test: p=1.000) or between CH2 and NEO/PER/INF/FET (Fisher's Exact Test: p=.1784).

Active lesions (mixed or active) were found on 70% (14/20) of individuals and were represented by individuals less than 1 years of age to adolescents between the ages of 15 and 17 years old. The majority of individuals (78.57%; 11/14) with active or mixed active ABG were from CH2. Exclusively healed periosteal bone was identified on the remaining 6 specimen and were represent by individuals between 5 and 17 years of age, again with CH2 members comprising the large number individuals (n=4).

Table 5.14 – Long Bones – ABG – Age Distribution

A-CAT		AFF	PRE	%OF n1	W/PW	A-CAT-COM	%OF n2	%OF N3
FET		0	6	0.00%		0.00%	0.00%	0.00%
PER/NEO		1	5	20.00%		20.00%	5.00%	1.41%
INF		1	2	50.00%	14.29%	50.00%	5.00%	1.41%
CHILD	CH1-Wean	0	7	0.00%			0.00%	0.00%
	CH1-PWean	1	8	12.50%		29.63%	5.00%	1.41%
	CH2	15	39	38.46%	35.29%		75.00%	21.13%
ADO		2	4	50.00%		50.00%	10.00%	2.82%
TOTAL	ALL	20	71					28.17%

N1=% Of specific age category; N2=% of those total affected (20); N3=% of total sample with long bones present (71)

Distribution of ABG – Individual Bones - General

There was a clear difference in the frequency of upper and lower limb bones showing evidence for ABG (see Table 5.15). When combined the upper limb was affected approximately 4.52% of the time while the combined bones of the lower limb were found to be affected slightly less than 5.5 time more often (24.87%). The difference between the limb regions was found to be significant (χ^2 with Yates Correction=27.983; df=1; Pvalue=.0001). Pair-wise comparisons between the tibia (most frequently affected bone) and the individual lower long bones found that

there was no significant difference between the tibia and fibula (χ^2 with Yates Correction=.313; df=1; Pvalue=.5757) but statistical significance was identified when the femur and tibia were compared (χ^2 with Yates Correction=3.845; df=1; Pvalue=.0499). The differences between the upper limb bones showed no significant in pair-wise comparisons.

Table 5.15 –Distribution of ABG – Upper and Lower Limb Bones

	ABG - LONG BONES - ALL					
BONE	SIDE	AFF	PRE	%OF N	COMB	%OF TOTAL AFF LB
HUMERUS	LEFT	1	36	2.78%	3.08%	3.57%
	RIGHT	1	29	3.45%		
ULNA	LEFT	2	33	6.06%	7.02%	7.14%
	RIGHT	2	24	8.33%		
RADIUS	LEFT	1	26	3.85%	3.70%	3.57%
	RIGHT	1	28	3.57%		
FEMUR	LEFT	7	39	17.95%	17.50%	25.00%
	RIGHT	7	41	17.07%		
TIBIA	LEFT	11	34	32.35%	32.84%	39.29%
	RIGHT	11	33	33.33%		
FIBULA	LEFT	4	25	16.00%	26.09%	21.43%
	RIGHT	8	21	38.10%		

Key: AFF=Affected; PRE=Present

Periosteal Bone Growth – Surface Distribution

All bones were assessed for the presence of ABG affect the external surface of the bone along the shaft. Each surface (anterior, posterior, medial and lateral) was scored for periosteal bone growth. In total, 1473 of 1476, individual surfaces were complete enough to be evaluated with only 8 surfaces that were not considered due to PMD. Table 5.16, below shows the total number of surfaces for each target surface with the medial surface being affected with the greatest frequency when compare to all other surfaces. The differences between the surfaces as related presence of periosteal bone were found not to be statistically significant.

Table 5.16 – ABG – SURFACE AFFECTED

	LONG BONES - ABG - DISTRIBUTION OF AFFECTED SURFACES - PER BONE/SIDE																		
	BONE	SD	A-AF	A-PR	%n1	C-ANT	M-AF	M-PR	%n2	C-MED	L-AF	L-PR	%n3	C-LAT	P-AF	P-PR	%n4	C-POS	%n5
U-APP	HUM	L	1	36	3%	3%	1	36	3%	3%	1	36	3%	3%	1	36	3%	3%	3%
		R	1	29	3%		1	29	3%		1	29	3%		1	29	3%		
	RAD	L	1	26	4%	4%	1	26	4%	4%	1	26	4%	4%	1	26	4%	4%	4%
		R	1	29	3%		1	29	3%		1	29	3%		1	29	3%		
	ULN	L	2	33	6%	5%	1	33	3%	5%	1	32	3%	4%	1	33	3%	4%	4%
		R	1	24	4%		2	24	8%		1	24	4%		1	24	4%		
L-APP	FEM	L	6	39	15%	14%	6	39	15%	14%	5	39	13%	13%	6	39	15%	16%	14%
		R	5	41	12%		5	41	12%		5	41	12%		7	41	17%		
	TIB	L	4	34	12%	15%	9	34	26%	29%	5	33	15%	18%	6	33	18%	20%	20%
		R	6	32	19%		10	32	31%		7	33	21%		7	33	21%		
	FIB	L	1	25	4%	7%	1	25	4%	13%	3	25	12%	17%	0	25	0%	2%	10%
		R	2	21	10%		5	20	25%		5	21	24%		1	20	5%		
TOT	ALL		31	369	8%		43	368	12%		36	368	10%		33	368	9%		10%

Key: U-APP=Upper Appendage; L-APP=Lower Appendage; HUM=Humerus; RAD=Radius; ULN=Ulna; FEM=Femur; TIB=Tibia; FIB=Fibula; SD=Side; L=Left; R=Right; A-AF=Anterior Affected; M-AF=Medial Affected; L-AF=Lateral Affected; P-AF=Posterior Affected; C-ANT=Combined-Anterior; C-MED=Medial Combine; C-LAT=Lateral Combined; P-ANT

Upper Limb – Humerus, Radius and Ulna

The bones of the upper limb (humerus, radius and ulna) were affected least frequently as a group and individually when compared to the lower limb. Slightly more than 3% (2/64) of the humerii were affected with ABG and both were from the same infant. No other members of other age cohorts were affected. The deposits of ABG on the left and right humerus were found to be thick and porous. There is no evidence for healing. The affected individual was of an age in which deposit of normal woven bone are to be expected. The particular specimen, however, when compared to samples of a similar age was shown to be outside of the normal amount of bone deposit. The radius showed a similar frequency for being affected at slightly less than 4% (2/56). Both radii were from the same individual in addition to being from the same infant as the affected humerus (see above) and two of the four ulna (see below). The abnormal bone growth affecting the left and right radii was active at the time of dead.

Of the 56 ulnae present four bones exhibited periosteal bone deposits. Of these 4, representing 3 individuals, one individual with bilateral lesions was aged to be approximately 1.5 years old while the other two individuals were both from the CH2 age category, with one of the two showing unilateral lesion and the other was not able to be assessed bilaterally due to PM loss of the left ulna. Active (mixed and active) lesions were found on 3 of the four ulnae. The remaining bone displayed healed deposits of periosteal bone. Two of the three bones with active lesions were associated with an infant (see above).

Lower Limb

Femur

Fifty of the 71 (70.42%) individuals representing a total of 80 femora, retained at least one femur that was observable. Of the 80 individual femurs 14 were shown to have ABG with 7 left femora were found to have ABG and 7 right femora were affected with ABG. Of these 50 individuals, 9 (18%) exhibited ABG on at least one femur while five of the six individuals (83.3%) with both femora present and observable displayed bilateral lesions. Of 320 surfaces observable 45 (14.06%) were displayed ABG, of which 12 of the 45 were healed at time of death with the remaining 32 showing active lesions or a mixture of active and healed deposits of ABG.

Tibia

Twenty-two of the 67 tibias (see Table 5.15), representing 13 individuals showed periosteal bone on the shaft of the tibia. Of these 13 individuals, 76.92% (n=10) were accounted for by members of CH2 group with 15.38% (n=2) and 7.69% (n=1) accounting for ADO and INF affected individuals, respectively.

Abnormal bone growth was found on the medial surface of shaft with the greatest frequency (~29%) compared to the anterior, lateral and posterior surfaces (15.15%, 16.66%, 19.69%, respectively). The differences between these surfaces and the medial surface were found not to be statistically significant (ANT/MED = χ^2 with Yates Correction=2.828; df=1; Pvalue=.0926; LAT/MED: χ^2 with Yates Correction=2.114; df=1; Pvalue=.1460; χ^2 with Yates Correction=1.031; df=1; Pvalue=.3099).

Active (mixed and active) periosteal bone deposits were identified on 8 (61.53%) of the 13 individuals. The remaining 5 individuals only exhibited healed lesions. All of the active ABG was in the form of woven porous bone. The thickness of deposit varied and while measurement were not always attainable, thick deposits of >1.5 mm was observed on at least on individual. This child displayed similar thick periosteal bone on the left and right femur (see above) and likely suffered from systemic infection. The extent of ABG coverage was observable in all cases as PMD inhibited a complete observation of individual bone. Distribution, however, ranges between almost complete coverage of the shaft to small patches of ABG deposits. Bilaterality was observed on 9 of the 13 (69.23%) individuals. Unilateral periosteal deposits were present on 15.38% (2/13) of tibiae while 2 individuals (15.38%) could not be assessed for ABG on the left and right tibia due to PMD.

Fibula

Fibula accounted for 12.46% of the total long bones evaluated and 21.43% (n=12) of the total long bones with ABG deposits. Individuals from CH2 comprised the majority of those with evidence of periosteal bone growth (6/9) with INF, CH1, and ADO each consisting of a single individual with ABG affecting the fibula. The present of bilateral lesions was observed in 3 of the 5 individuals with the left and right fibulae present. The remaining 4 could not be assessed for bilateral lesion due post-mortem loss or damage to one of the fibulae. Active (mixed and active) lesions were observed on 7 of the 12 fibula with the remaining 5 fibula showing exclusively healed deposits of ABG. The medial and lateral surfaces showed the highest frequency of periosteal bone deposits with 6 of 11 and 8 of 12 surfaces affected, respectively. There was no statistical significant difference between the medial and lateral surface (χ^2 with

Yates Correction=.028; df=1; Pvalue=.8671) or between the lateral surface and the anterior surface (χ^2 with Yates Correction=2.685; df=1; Pvalue=.1013). There was however, a significant difference between the lateral surface and posterior surface (χ^2 with Yates Correction=5.753; df=1; Pvalue=.0.165). The most severe deposits were found on the left and right fibula of the single infant, which was incidentally the same infant that was discuss above.

Other Post-Cranial Material

Post-cranial skeletal, in addition to the material discussed above was also found to ABG present on some of the elements. Of the 102 individuals 78 retained post cranial bones (includes those with long bones). Of these 78, 6 (7.69%) retained only non-long bones post-cranial material. In total excluding long bones, 1267 individual bones, comprised of vertebrae, elements of the pectoral girdle and thorax, and hand and foot material, were examined for ABG of which 19 (1.5%), representing 7 individuals, displayed ABG. Table 5.17 displays the distribution of affected post-cranial non-long bone material. With the addition of long bones the overall prevalence of affected bone increases to slightly more the 4.5% (75/1636).

Table 5.17 – ABG Post-Cranial Non-Long Bones

REGION	BONE	AFF	PRE	% OF N1	% OF N2
VERTEBRA	CER	0	129	0.00%	0.81%
	THR	1	225	0.44%	
	LUM	0	79	0.00%	
	SAC	3	61	4.92%	
PECT-GIRDLE	CLA	0	48	0.00%	2.13%
	SCA	2	46	4.35%	
THORAX	STE	0	11	0.00%	2.19%
	RIB	7	309	2.27%	
INNOMINATE	PEL	2	70	2.86%	2.86%
HAND	MC	3	75	4.00%	4.00%
FOOT	MT	0	50	0.00%	0.72%
	TAR	1	89	1.12%	
PHALANGES	PHA	0	75	0.00%	0.00%
TOTALS		19	1267		1.50%

Key: N1=% of affected out of total for specific element; N2=% of affected out of total a specific type of bone

5.3.3 Combined Results – Cranial and Post-Cranial - ABG

Table 5.18 displays the distribution of abnormal bone growth for the entire sample irrespective of the affected regional location (i.e cranial). Of the 102 individuals in the Simrium sample, 48 (47.05%) individuals had a least one bone that displayed abnormal bone growth. Of those affected (n=48), CH2 showed the highest prevalence (70.83%) compared to all other age categories, with CH1 (16.6%) and ADO (8.33%) showing the next two highest rate of being affected. Perinatal and infant individuals were both affected at a rate of <3% of those of the total individuals with evidence of ABG. When compared the difference between affected CH1 and affected CH2 was found to be statistically significant (Yates χ^2= 24.455 df=1; p=<.0001) as was the difference between CH2 and ADO (Yates χ^2= 36.632 df=1; p=.0001). The difference between CH1 and ADO, however was found not to be significant (Yates χ^2= .857 df=1; p=.3545).

Table 5.18 – ABG –Cranial and Post Cranial Distribution

BEHAVIORAL GROUP	AGE	AFF	PRE	% OF N1	% OF N2	% OF N3	% OF N4
	FET	0	6	0.00%	0.00%	0.00%	0.00%
PRE-WEANING	PER	1	3	33.33%	35.71%	33.33%	0.98%
	NEO	0	2	0.00%		0.00%	0.00%
	INF	1	2	50.00%		50.00%	0.98%
	CH1	8	21	38.10%		51.85%	41.18%
POST-WEAN	CH2	34	60	56.67%	55.88%		
	ADO	4	8	50.00%		50.00%	3.92%
	TOTAL	48	102				47.06%

Note: of the 28 individual within the 'P-WEAN A-CAT 18 were ≤3 years of age which was the cut-off for weaning for this sample.

Of the 18 individual of weaning age 9 (50%) were found to exhibit abnormal bone growth with post-weaning individuals showing the same frequency for those affected with 39 of the 78 displaying ABG. The difference was found not to be significant (Yates χ^2= 0.00 df=1; p=.0000).

Of the 48 with ABG, 27 (56.25%) individuals retained both cranial and post-cranial material, of which 5 (18.51%) exhibited ABG on both cranial and post-cranial material. All of the individuals with both regions affected were between 6 and 14 years of age (CH2). Thirteen of the remaining twenty-two (59.09%) individuals with both regions present exhibited only cranial ABG while post-cranial ABG only was found on the remaining 9 (33.33%) individuals. The difference between individuals with both regions affected and those with only single regions affected was found to be statistically significant (Yates χ^2= 18.963 df=1; p=<.0001). As noted above all individuals displaying ABG on cranial and post-cranial material were all members of the CH2 age cohort. Comparison of the average age for those with abnormal bone growth affecting both regions compared to the average age for individuals with one region affected was found not to be statistically significant (T-Test CI=95%; p=.9409; t=.0749; df=25; SE=2.256).

5.4 Dental Pathology Results

5.4.1 Dental Caries

Introduction and Methods

Caries were evaluated according present/absent, tooth type, tooth class, surface affected, position, and severity. All dentition (deciduous and permanent) were included in this assessment. The general parameter for caries assessment required that the tooth be completely erupted from the alveolar socket and in occlusion. Teeth that were not erupted or partially emerged from their sockets were not considered for this analysis as exposure to the oral environment is necessary for the formation of cavities.

Of the 61 individual with dental material 58 individuals retained dentition that was suitable for assessment of caries. These 58 specimens were represented by 717 permanent and deciduous teeth fitting the requirement of being fully erupted and in occlusion. Of the 58 non-adults, 10 (17.24%) fell into the age category of CH1, 42 (72.41%) were between the ages of 6 and 14 (CH2) and 6 (10.34%) were adolescents.

For purposes of recording caries each tooth (enamel and root surface) was divided in to five regions/surfaces; 1. Occlusal; 2. Distal; 3. Mesial; 4. Lingual; 5. Buccal/Labial. Caries were recorded according to the surface and the placement/position (root; enamel surface; CEJ; interproximal; mixed) in which they occurred. The severity for each lesion was scored on a scale of 1 to 3 with 1 being a small penetration of the enamel/root surfaces, 2 indicating a moderate size lesion and a score of 3 determined by a lesion that had destroyed a significant proportion of the crown/root. The methods used for lesion identification and recording are based on those found in Buikstra and Ubelaker (1994) with some modification. Dark stains, often thought to be

a beginning stage of lesion formation, were not included in the in final statistics for carious lesions as these features can have alternate non-carious origins.

Caries Results for All Age Groups and Tooth Types

When evaluated for caries, 14 of the 58 (24.14%) individuals exhibited evidence for lesions. The distribution according to age categories identified 1 of the 10 members of CH1 (1-5 years of age), 12 of 42 CH2 (6-14 years of age) individuals and 1 of the 6 adolescents (15-17 years of age) had teeth with carious lesions. Comparisons between all age groups found no significant difference in the prevalence of caries between each group. Of the 717 teeth, 31 (4.32%) were found to exhibit carious lesions. Table 5.20 displays the distribution of caries according to tooth type and tooth class in relationship to the entire sample (N=717). As expected, molars were affected with the highest frequency (3.35%) with all other classes of teeth (PM, CA, IN) showing a frequency of less than 1%.

Pair-wise comparisons using the Fisher's Exact Test were conducted for between all tooth classes and it was found that in all crosses there was no significant difference between the frequency of caries and tooth type (see Table 5.19 for results).

Table 5.19 – Statistical Comparison – Tooth Type

	(1)	(2)	P-VALUE	SIGNIFICANT
(1)MOL X (2)CN	24/369	2/90	0.1332	NO
(1)MOL X (2)IN	24/369	4/157	0.0875	NO
(1)CN X (2)IN	2/90	4/157	1	NO
(1)MOL[1] X (2)PM	7/207	1/101	0.2803	NO

[1]Total MOL is comprised of permanent molars only.
Key: MOL=Molar; CN=Canine; IN=Incisor; PM=Premolar

When viewed as per-type of tooth, molars again exhibited the highest frequency of being affected at 6.5% (24/369) with canines and incisors between 2%-3% affected. Out of 101 premolars only 1 or .99% was affected.

Table 5.20. Caries Distribution by Tooth Class and Dentition Type

	DECIDUOUS		PERMANENT		COMBINED		SAMPLE	
	AFF/PRES	%	AFF/PRES	%	AFF/PRES	%	AFF/PRES	%
MOLAR	17/162	10.49%	7/207	3.38%	24/369	6.50%	24/717	3.35%
PRE-MOLAR			1/101	0.99%	1/101	0.99%	1/717	0.14%
CANINE	1/32	3.13%	1/58	1.72%	2/90	2.22%	2/717	0.28%
INCISOR	1/27	3.70%	3/130	2.31%	4/157	2.55%	4/717	0.56%
TOTALS	19/221	8.60%	12/496	2.42%			31/717	4.32%

Key: AFF=Affected; PRES=Present

Table 5.21 displays the distribution caries within the group of individuals (n=14) that exhibited at least one lesions according to tooth type and tooth class. In total 152 teeth represented the 14 individuals that exhibit carious lesions. Of the 152 teeth that were observable 34.8% (n=53) were deciduous teeth with the remaining 99 (65.13%) teeth being of the permanent type. Caries were found to affect 31 of the 152 teeth (20.39%).

Table 5.21 – Caries Distribution

	DECID		PERM		COMBINED	
TOOTH TYPE	AFF/PRES	%	AFF/PRES	%	AFF/PRES	%
MOLAR	17/47	36.17%	7/54	12.96%	24/101	23.76%
PRE-MOLAR			1/13	7.69%	1/13	7.69%
CANINE	1/4	25.00%	1/9	11.11%	2/13	15.38%
INCISOR	1/2	50.00%	3/23	13.04%	4/25	16.00%
TOTALS	19/53	35.85%	12/99	12.12%	31/152	20.39%

Key: AFF=Affected; PRES=Present

Lesions were found to affect deciduous teeth at a higher frequency when compared to permanent teeth. The difference between these two groups types of dentition was shown to be highly statistically significant (χ^2=11.971; df=1; P value=0.0005).

Affected Surfaces

In order to gain a better understanding of the distribution of lesions on a tooth, the specific surface and position (location on a specific surface) was recorded. Table 5.22 displays the surfaces affected by caries. Of the five surfaces that were evaluated for evidence of carious lesions, the BUC/LAB surface was affected (per-tooth basis) with the greatest frequency (35.48%), followed by the mesial and distal at 29.02% and 22.58%, respectively. The lingual and occlusal surfaces were found to have been the least affected by caries with percentages 9.67% and 6.45%, respectively.

Affected Positions

Caries distribution relation to surface position can be found in Table 5.22**.** The positions most affected by lesions are the enamel surface (crown only does not include the interproximal position) and the root surface at 37.14% and 31.43%, respectively, followed by the interproximal, CEJ and mixed surfaces. The relationship to surface position can be found in Table 5.23.

Severity

As noted above severity (see Table 5.22) was scored based on a scale of 1-3. Of the 35 lesions identified the majority were found to show minimal penetration (SCR 1) of the enamel or root surface (n=19 or 54.28%). The most severe lesions (n=5; 14.29%) were present at a slightly lower frequency than moderate sized lesions (n=7; 20%).

Table 5.22 – Caries Distribution – Location/Severity/Position

BCINV	AGE	T#	CAR-SCR	SUR	POS	CR-CNT	T-TYPE	D-TYPE	T-CNT
10C-2	CH2	59	1	LING	ES	1	D-MOL	D-MAX	1
10M-6	CH2	51	2	DIST	CEJ	1	D-MOL	D-MAX	1
11N-EXT-1	CH1	55	1	BUC/LAB	ES	1	D-IN	D-MAX	1
11N-EXT-1	CH1	58	1	BUC/LAB	ES	1	D-CA	D-MAX	1
12ANW-QUAD-1	CH2	62	1	BUC/LAB	R	1	D-MOL	D-MAND	1
12ANW-QUAD-1	CH2	69	1	BUC/LAB	R	1	D-MOL	D-MAND	1
5K-1	CH2	3	1	OCCL	ES	1	MOL	MAX	1
5K-1	CH2	61	1	MESI	CEJ	1	D-MOL	D-MAND	1
5K-3	CH2	51	1	BUC/LAB	R	1	D-MOL	D-MAX	1
7N-1	CH2	60	3	MESI	ES	1	D-MOL	D-MAX	1
8J-1	CH2	59	1	MESI	ES	1	D-MOL	D-MAX	1
8N-2	CH2	61	2	DIST	ES	1	D-MOL	D-MAND	1
8N-2	CH2	70	2	DIST	ES	1	D-MOL	D-MAND	1
8N-3	ADO	14	1	OCCL	ES	2	MOL	MAX	1
8N-3	ADO	14	1	DIST	INPRX	1	MOL	MAX	0
8N-3	ADO	19	1	MESI	INPRX	1	MOL	MAND	1
8N-3	ADO	61	1	DIST	ES	1	D-MOL	D-MAND	1
9N-EXT-1	CH2	59	2	DIST	ES	1	D-MOL	D-MAX	1
9N-EXT-5	CH2	14	1	DIST	R	2	MOL	MAX	1
9N-EXT-5	CH2	15	2	BUC/LAB	RE-CEJ	1	MOL	MAX	1
9N-EXT-5	CH2	51	3	OCCL	ES	1	D-MOL	D-MAX	1
9N-EXT-5	CH2	70	1	MESI	CEJ	1	D-MOL	D-MAND	1
9N-EXT-6	CH2	7	2	BUC/LAB	R	1	IN	MAX	1
9N-EXT-6	CH2	8	1	BUC/LAB	R	1	IN	MAX	1
9N-EXT-6	CH2	14	1	LING	R	1	MOL	MAX	1
9N-EXT-6	CH2	22	1	BUC/LAB	R	1	CA	MAND	1
9N-EXT-6	CH2	25	2	BUC/LAB	R	1	IN	MAND	1
9N-EXT-6	CH2	28	1	BUC/LAB	R	1	PM	MAND	1
9N-EXT-7	CH2	3	1	MESI	INPRX	1	MOL	MAX	1
9N-EXT-7	CH2	51	3	MESI	INPRX	1	D-MOL	D-MAX	1
9N-EXT-7	CH2	60	3	MESI	INPRX	1	D-MOL	D-MAX	1
9N-EXT-7	CH2	70	3	MESI	INPRX	1	D-MOL	D-MAND	1
9N-EXT-7	CH2	70	1	DIST	INPRX	1	D-MOL	D-MAND	0

Table 5.23 – Caries Distribution in Relationship to Tooth and Affected Surface

	Enamel Surface		Root		Interproximal		Cement-Enamel -Junct		Mix	
	AFF/T-CAR	%	AFF/T-CAR	%	AFF/T-CAR	%	AFF/T-CAR	%	AFF/T-CAR	%
MOL	11/35	31.43%	6/35	17.14%	7/35	20.00%	3/35	8.57%	1/35	2.86%
PM	0/35	0.00%	1/35	2.86%	0/35	0	0/35	0	0/35	0
CA	1/35	2.86%	1/35	2.86%	0/35	0	0/35	0	0/35	0
IN	1/35	2.86%	3/35	8.57%	0/35	0	0/35	0	0/35	0
TOTALS	12/35	37.14%	11/35	31.43%	7/35	20.00%	3/35	8.57%	1/35	2.86%

Key: MOL=Molar; CN=Canine; IN=Incisor; PM=Premolar; AFF=Affected

5.4.2 Dental Enamel Hypoplasia

Introduction and Methods

The results for hypoplasia assessment are found below. Evidence for enamel hypoplastic defects for all age categories was evaluated for all individuals with observable deciduous and permanent teeth. Each tooth was surface was observed for evidence for hypoplasia in the form of linear horizontal grooves, pits (single and or multiple). Measurements were taken of all linear horizontal grooves for the purpose of determining the age at which the defect formed. The methods used for measurement and protocol used for calculating age are discuss below.

General Distribution of Enamel Hypoplasia – According to Age

Slightly less than 60% (n=61) of the total sample (N=102) retained dental material that was suitable for assessment of enamel hypoplasia. Of these 61 non-adults, 37 (60.66%), represented by individuals in Child 1 (CH1), Child 2 (CH2) and ADOL (ADO) age cohorts, were found to have at least one tooth affected by enamel hypoplasias. The distribution according to age can be found in Table 5.24. Of the nine children that were of weaning age (<3yrs of age-see isotope chapter), only one individual showed hyoplastic defects, while 2 of the 4 children of post-weaning age from the CH1 cohort exhibited hypoplasias. The majority of individuals affected are those from the CH2 age cohort. Within this group, individuals aged to be between 6 years of age show the highest frequency of being affected (n=7), followed by children 13 years of age (n=6). Together these two groups comprise approximately 45% of CH2. Of the 37 individuals with hypoplastic defects, 34 (34/37: 91.89%) exhibited evidence for only LEH, while one individual (2.70%) exhibited only pit defects and the remaining two children (5.40%) were found to have a mixture of pit and linear type defects.

Comparison Between Age Cohorts

When individuals in the two major child categories (CH1 and CH2) were compared it was found that the difference in frequency of affected was highly significant (Fisher Exact Test: p=.0035). No significance in for hypoplasia frequency was found when CH2 and ADO groups were compared (Fishers Exact Test: p=1.000). There was, however, a significant difference found between ADO and CH1 (Fishers Exact Test: p=.0408).

Table 5.24 – Hypoplasia – Age Cohort

A-CAT		AFF	PRE	% of n	Com % of n	% of N	Com%N
INF		0	1	0.00%		0.00%	
CH1	WN	1	9	11.11%	23.08%	1.64%	21.31%
	PT-WN	2	4	50.00%		3.28%	
CH2		29	41	70.73%		47.54%	
ADO		5	6	83.33%		8.20%	
TOTAL		37	61			60.66%	

n= total number of individuals for specific age/sub-age category; N=total number of individuals (61) with dental material suitable for EH assessment

Individual Teeth - Hypoplasia

In total there were 1055 individual teeth present representing the 61 individuals, but only 860 (81.516%) fit the parameter for analysis; the remaining teeth were not observable due a lack of eruption. These teeth, however, depending on the status of formation could be evaluated if they were removed from their crypts. In the sections below, the results for each tooth class will be discussed individually.

Incisors

Incisors (deciduous and permanent) account for approximately 21.627% (n=186) of the total sample of teeth (n=860) assessed for enamel hypoplasia. Of these 186, 86 (46.23%) were maxillary and 100 (53.67%) were from the mandible. Deciduous teeth comprised approximately 15.60 % (n=29) of the incisors while permanent incisors represented the majority of teeth in this

class (n=157: 84.40%). Slightly more than 47% of incisors (n=75) had enamel hypoplasictic defects none of which were from deciduous dentition (see Table 5.25). A total of 104 hypoplastic defects were identified of which the majority were linear horizontal type (100/104) and the remaining 4 (3.85%) were pit-form defects. The distribution of affected teeth according to dentition type, tooth type (maxillary or mandibular), and tooth position (lateral or central) is found below.

Table 5.25 – Hypoplasia Distribution – Tooth Class/Tooth Type

T-Class	T-Type	AFF	PRES	% of n	CB % of n
MOL	DEC	0	174	0.00%	1.66%
	PERM	7	248	2.82%	
IN	DEC	0	29	0.00%	40.76%
	PERM	75	157	47.70%	
CA	DEC	3	38	7.89%	47.20%
	PERM	56	87	64.37%	
PM	PERM	48	129	37.21%	37.21%
Total		189	860	21.98%	

Key: n=total number of teeth for specific tooth class; Aff=all defect types

Mandible Incisors

Hypoplasia defects were identified on 43% (43/100) mandibular teeth (see Table 5.26), all of which were permanent. Thirty-eight percent of the lateral incisors (permanent and deciduous) (19/51) were affected by hypoplastic defects. The frequency for affected central incisors (24/49) was found to be slightly higher (48.979%) but not statistically significant (Yates-Two Tailed p=.3126) when compared to lateral incisors. A total of 62 enamel lesions were identified on the mandibular incisors. The lateral incisors accounted for approximately 48.275% (n=28) lesions while the central incisors showed a slightly higher frequency of lesions at 51.724% (n=34). LEH type defects accounted for approximately 93.54% (58/62) lesions identified while the remaining 6.45% or 4 defects were pit form hyoplasias. The difference in the frequency was found to be significant (Yates: p=.0001).

Table 5.26 – Hypoplasia – Mandible - Distribution

MAND-IN	T#	AFF	PRE	%of n	%of n1	%ofn2	%of N
LATERAL	23	12	22	54.55%			
	26	7	16	43.75%	50.00%		
	64	0	7	0.00%			
	67	0	6	0.00%	0.00%	37.25%	43.00%
CENTRAL	24	10	22	45.45%			
	25	14	21	66.67%	55.81%		
	65	0	3	0.00%			
	66	0	3	0.00%	0.00%	48.98%	

Key: n=% of Tooth#; n1=% of Dentition Type; n2=% of affected tooth position; N=% of affected out of tooth class for Mandible

Maxillary Incisors

Of the 86 maxillary incisors present for analysis, 32 (37.209%) had hypoplastic lesions (see Table 5.27). Lateral maxillary incisors accounted for approximately 45.348% (n=39) of all upper incisors. Of these 39, 14 (35.897%) exhibited hypoplasic defects. Approximately 45% central permanent and deciduous maxillary incisors had hypoplasias. As was found with the lateral incisors, no deciduous teeth were affected. Comparison of the frequency of hypoplasia between the lateral and central incisors of the maxilla did not show any significance (Yates: p=1.0000). Forty-two enamel defects were identified all of which were linear in form. No pits were found. Of the 42 defects, 16 (38.095%) affected the lateral and 26 (61.904%) affected the central maxillary incisors. The difference was found to be statistically significant (Yates: p=.0489).

Table 5.27 – Hypoplasia – Maxilla - Distribution

MAND-IN	T#	AFF	PRE	%of n	%of n1	%ofn2	% of N
LATERAL	7	7	14	50.00%	38.89%	35.90%	37.21%
	10	7	22	31.82%			
	54	0	2	0.00%	0.00%		
	57	0	1	0.00%			
CENTRAL	8	8	22	36.36%	45.00%	38.30%	
	9	10	18	55.56%			
	55	0	4	0.00%	0.00%		
	56	0	3	0.00%			

Key: n=% of Tooth#; n1=% of Dentition Type; n2=% of affected tooth position; N=% of affected out of tooth class for Maxilla

Canines

Deciduous and permanent canines represented approximately 14.41% (n=124) of the total dental sample assessed for hypoplasia. Maxillary canines (n=66) accounted for slightly more than half of the sample (53.225%) with mandible canines representing approximately 46.774% (n=58) of the total. Deciduous upper and lower canines comprised 22.58% (n=28). Evidence of enamel hypoplasias were found on approximately 47.58% (59/124) of canines (see table 5.25) with upper mandibular canines showing a slightly higher frequency of defects (48.275) compared to the maxillary canines (46.969%). No significant difference was identified (Fishers Exact Text: p=1.000).

Maxillary Canines

Slightly less than 47% (n=31) of maxillary canines (deciduous and permanent) had enamel hypoplasias. Of the 31 affected maxillary canines, all were permanent canines with 15 from the right and 16 from the left. The distribution of defects showed a similar frequency between the left (62.5%) and right upper canines (66.66%). No significant difference was found when the defect prevalence between the left and right maxillary canines was compared (Fishers Exact

Test: p=1.000). Maxillary canines accounted for 44 (51.162%) of the 86 enamel defect found to affected this class of tooth. All of the hypoplasia on the maxillary dentition represent LEH. No pits were found.

Mandibular Canines

Of the 58 mandibular canines assessable for hypoplasia analysis, 28 (48.275%) were found to have enamel defects. The majority of those teeth affected were permanent left and right canines (n=25). Deciduous teeth did exhibit enamel defects, albeit at a much lower frequency (15%) when compare to permanent canines (65.789%). The difference between affected deciduous and permanent canines was found to be extremely significant (Fisher Exact Test: p=.0003). Comparison of lesion frequency between the left and right sides, however, did not exhibit any significant (Fishers Exact Text: p=.7993). With the exception of four pit-type hypoplasias on three deciduous teeth the remaining 38 (90.476%) hyoplasias were LEH. The difference between the types of lesions was found to be significant (Fishers Exact Test: p=.0001).

Premolars

Premolars account for approximately 14.883% (n=128) of the total sample of dentition used for hypoplasia assessment (see Table 5.25). The average age for individuals with affected premolars was found to slightly greater than 11 years old (11.23 yrs) with a range of 6 (CH2) to 16.13 (ADO) year of age. Maxillary and mandibular premolars were represented equally in terms of overall quantity each with 64 teeth. Forty-eight of the 128 premolars (37.5%) had hypoplasia and represented a total of 18 individuals.

Evidence of enamel hypoplasias was found on 22 of the 64 maxillary premolars (34.375%) and on 26 of the 64 mandibular premolars (40.625%). When compared, no significant difference (Fisher Exact Test: p=.5841) was found between the frequency of hypoplasia affecting the maxillary and mandibular premolars. The distribution of enamel defects affecting premolars can be found in Table X. In total 58 lesions were identified, all of which were linear-type defects. Of the 48 teeth affected, 10 (20.83%) exhibited two defects with the remaining 38 (79.16%) premolars showing only single lines. The frequency of enamel defects was highest among the upper left PM3 (T12) and the lower right PM3 (T28) both of with showed a rate of 43.75% affected. The lowest frequency (29.41%) for the premolar class was associated with the maxillary left PM4 (T13). Comparison between the premolars with the highest and lowest hypoplasia frequency showed no significant difference (Fishers Exact Test: p=.4813).

Table 5.28 – Hypoplasia – Premolar - Distribution

T-CODE	T#	AFF	PRES	FRQ	FRQ2	FRQ-P4	FRQ-P3	COMB
U-RP4	4	4	13	30.77%	32.26%			
U-RP3	5	6	18	33.33%		30.00%	38.24%	34.38%
U-LP4	13	5	17	29.41%	36.36%			
U-LP3	12	7	16	43.75%				
LO-LP4	20	6	15	40.00%	40.63%			
LO-LP3	21	7	17	41.18%		38.71%	42.42%	40.63%
LO-RP4	29	6	16	37.50%	40.63%			
LO-RP3	28	7	16	43.75%				

Maxillary Premolars

Of the 64 maxillary premolars, 22, or 34.375%, had enamel hypoplasia (see Table 5.28). The upper right premolars (T4 and T3) had a combined frequency of approximately 32% which was slightly less compared to the frequency of hypoplastic defect affecting the left premolars (~36%). No statistical difference, however, was found when these groups were compared (Fishers Exact Test: p=.7960). A similar finding was observed when the affected left and 3rd premolars were compared to the affected right and left 4th premolars (Fisher Exact Test: p=.6004). Linear-type

enamel hypoplasias accounted for all 26 lesions affecting the maxillary premolars. The distribution of lesions per-specific maxillary premolar did not show any significant difference in the total number of defects.

Mandibular Premolars

Twenty-six of the 64 mandibular premolars exhibited enamel hypoplasias. There was an even distribution of affected premolars between the left (n=13) and right (n=13) sides. Slightly fewer premolar # 4 (left and right side) were affected (n=12) compared to the number of affected P3 teeth (n=14). Comparisons of the frequency of affected tooth type (p3 vs p4) were shown not to be statistically significant (Fishers Exact Test p=.8035). As was found with the maxillary premolars, linear-type hypoplastic defects account for 100% of the lesions affecting the mandibular premolars. The distribution is displayed in Table 5.28. Comparisons between the number of lesion affecting the 3rd and 4th premolars did not identify any statistically significant difference between the two groups (Fisher Exact Test: p=.4536).

Molars

Seven of the 248 (2.82%) molars showed evidence for hyoplastic defect all of which were horizontal linear defects. Of the 7 affected molars 5 were maxillary and 2 were from the mandible. Upper and lower 2nd molars were affected more often compared to 1st molars. There were no instances in which 3rd molars were show to have been affected by hyoplasias.

Hypoplasia Measurements

The age of defect formation was calculated for all LEH based the formula developed by Walker as presented by Wheeler (2010) and Lovell and Whyte (1996). The distant between each LEH

and the CEJ was measured and recorder for all affected teeth, with the exception of those teeth with LEH that suffered post-mortem damage or other factor that did not allow for measurements. Of the 247 LEH identified 15.38% could not be measured due to PMD to the measurement origin(s).

Incisors -Measurements

One hundred and four hypoplasias were identified on the combined maxillary and mandibular dentition. Of these, 100 were linear horizontal defects a four were pit-form type defects which were not subjected to measurement analysis. As a result of PMD, 13 (13%) of the 100 LEH could not be measured and were therefore removed from the measurement sample. Table 5.29 displays the collective average age for the development of LEH according to the position within the dental arcade.

The lateral and central incisors show a difference in the average age for the formation of the first LEH (see Table 5.29) of approximately .8 years (between 9-10 months). The difference between the average ages were found to be extremely significant (T-Test CI=95%; p=.0001; df=26). The formation of the second hypoplasia for maxillary lateral and central incisors had an average age of 3.27 and 3.19, respectively, a difference of approximately .06 years. The difference was found not to be statistically significant (T-Test CI=95%; p=.8432; df=7).

The development of all hypoplasias affecting the mandibular incisors all had an average age that fell below 3 years of age. The earliest defect was assessed to have developed at approximate 2.19 and 2.24 years for the lateral and central incisors, respectively. The formation of the second

defect was observed to have formed around the age of 2.72 for the lateral incisors and 2.48 for the central incisors. Lastly, teeth with a third hypoplasia saw the average age of formation at approximately 2.98 (lateral incisors) and 2.69 (central incisors) years of age. In all cases no significant difference was found when the average age was compared between the lateral and central incisors for the timing of the formation of the 1st, 2nd, and 3rd, hypoplastic defects (L1=T-Test CI=95%; p=.7805; df=36: L2=T-Test CI=95%; p=.4354; df=6: L3=T-Test CI=95%; p=.2774; df=2)

Comparisons of the age of formation for the 1st and 2nd hypoplasia across dentition types (maxilla and mandible) for incisors found the difference in average age was significant for the temporal development of hypoplastic lesions (L1=T-Test CI=95%; p=.0025; df=64: L2=T-Test CI=95%; p=.0176; df=15).

Table 5.29 – Hypoplasia – Age of Formation – Incisors

D-TYPE	T-Code	T#	A-AGE L1	A-AGE L2	A-AGE L3	D-TYPE COM-L1	D-TYPE COM-L2	D-TYPE COM-L3
MAXILLA	LAT-IN	7 & 10	3.08	3.27		2.65	3.21	
	CENT-IN	8 & 9	2.28	3.19				
MANDIBLE	LAT-IN	23 & 26	2.19	2.72	2.98	2.22	2.63	2.84
	CENT-IN	24 & 25	2.24	2.48	2.69			
COMBINED	LAT&CENT	7-10; 23-26	2.40	2.94	2.84			

KEY: LAT-IN=Lateral Incisor; CENT-IN=Central Incisor; T#=Tooth Number; A-AGE L1= Average age for first hypoplasia formation; D-Type=Dentition Type; L1=Line (defect) 1-First defect to form; L2=Second defect to form; L3=Third defect to form

Canines – Hypoplasia

In total there are 86 enamel hypoplasias affecting 59 canines. Of these 86 defects, 82 were of the linear horizontal type defects with the remaining 4 being pit-type lesions. No measurements were attempted on the non-linear-type defects and therefore, these four deciduous teeth were removed from measurement analysis. Of the 82 LEH defects identified, 72 (87.80%) were measurable.

These 10 defects could not be measured due to PMD. The average age of defect formation for the earliest defect (for maxillary and mandibular canines combined) was found to occur around the age of 3 years old with a range of .8-6 years of age. The formation of a second LEH was found to occur around the age of 4, while formation of a third lesion was calculated to have formed around the age of 5 years of age (see Table 5.30).

The average age for the formation of the earliest lesion for maxillary canines (T6 & T11) was found to have occurred at approximately at 3.21 years of age which was slightly older compared to the average age (3.18) for the development of the 1st lesion affecting the mandibular canines (T22 & T27). There was no statistically significant difference between the timing of the formation of the first LEH between the upper and lower canines (T-Test CI=95%; p=.9161; df=44).

There was a larger difference in the average age for the formation of the second lesion affecting the canines of the maxilla (3.61 years) and mandible (4.09 years) compared to the 1st lesion (see Table 5.30), but no significant difference was identified (T-Test CI=95%; p=.2985; df=20). The difference in the average age for the development of the 3rd enamel defect affecting the upper and lower canines (4.0 and 5.47 years old, respectively) was approximately 1.47 years. When compared, however, the difference in average age was found to be not statistically significant (T-Test CI=95%; p=.3331; df=2).

Table 5.30 – Hypoplasia – Age of Formation – Canine

D-TYPE	T-Type	T#	A-AGE L1[1]	A-AGE L2[1]	A-AGE-L3[1]
MAXILLA	CA	6&11	3.21	3.61	4.00[2]
MANDIBLE	CA	22&27	3.18	4.09	5.47[2]
COMBINED	CA	6,11,22,27	3.20	3.88	4.73

Key: [1]Age in years-Rounded to 2 decimals; [2]Only two teeth represented; T-Type=Tooth Type; L1=Line (defect) 1-First defect to form; L2=Second defect to form; L3=Third defect to form

Premolars

Of the 58 LEH affecting maxillary and mandibular premolars 44 were subjected to measurement while the remaining 14 were excluded from hypoplasia measurement due to PMD. Table 5.31 displays the result of the average age of hypoplasia formation for premolars according to position within the dental arcade. Maxillary PM3 (T5&12) showed an average age of formation for the first lesion at approximately 4.22 years of age while the average for formation of the first lesion of PM4 (T4&13) was found to be develop at approximately 4.94 years of age. Comparison between the mean age of formation for the first hypoplasia for PM3 and PM4 found no significant difference (T-Test CI=95%; p=.1003; df=13). Formation of the second lesion of maxillary PM1 and PM2 was found to have occurred at an approximate age of 4.6 (only 2 teeth) and 4.84 (one tooth).

The formation of first lesion for mandibular PM3 (T21&28) was found to occur at the slightly younger age of 3.72 when compared to the maxillary PM3 for the earliest forming enamel hypoplasia. The lower PM2, however, exhibited the opposite pattern with age of formation of the earliest defect at approximately 5.62 years of age or a litter over .5 years older than the average age for maxillary PM4 (4.94 years). Comparison between the average age of maxillary PM3 and PM4 formation of the first lesion found the difference to be extremely significant (T-Test CI=95%; p=.0001; df=18). The age of formation for the second lesions for PM1 and PM2 of the

mandible was found to be approximately, 4.68 and 5.95 (only 2 teeth), respectively and the difference was found not to be statistically significant (T-Test CI=95%; p=.1109; df=3).

Comparison between the maxilla and mandibular premolars for formation of the first lesion found that there was no significant difference between average age (T-Test CI=95%; p=.9330; df=33). Similarly, no significant difference was found between the average age for the development of the second enamel hypoplasia between the maxillary and mandibular premolars.

Table 5.31 – Premolars – Hypoplasia Formation – Average Age

D-TYPE	T-Code	T#	A-AGE L1[1]	A-AGE L2	D-TYPE COM-L1	D-TYPE COM-L2
MAXILLA	PM4 (P2)	4&13	4.94	4.84[2]		
	PM3 (P1)	5&12	4.22	4.60[3]	4.61	4.68
MANDIBLE	PM4 (P2)	20&29	5.62	5.95[4]		
	PM3 (P1)	21&28	3.72	4.68	4.57	5.19

Key: [1]Age in years-Rounded to 2 decimals; [2]Only one tooth represented; [3]Only two teeth represented; [4]Only two teeth represented;
L1=Line (defect) 1-First defect to form; L2=Second defect to form; L3=Third defect to form

Chapter 6

Paleodiet and Stable Isotopic Analysis

6.1 Introduction and History of Isotopic Use in Archaeology

The analysis of stable isotopes was incorporated into this dissertation for the purpose of identifying dietary trends and weaning behavior and their relationship to morbidity in a sub sample of the Sirmium collection. The results of this study will be discussed in this chapter and subchapters. This work is meant to supplement and enhance the archaeological, historical and bioarchaeological (skeletal and dental analysis) data gathered for this dissertation. Prior to discussing the results of this specific population (sub-sample), I will briefly discuss the history of stable isotopes and the principle behind isotopic research in bioarchaeology (specifically carbon and nitrogen) and their importance as a supplemental method for the reconstruction of past human behavior. In closing, I will discuss some of the limitations, specifically in relation to this dissertation sample, and the future goals for isotopic research regarding the Sirmium collection.

Stable Isotope Research in Archaeology and Bioarchaeology

For the last 30+ years the stable isotopic analysis of bone and teeth has greatly added clarity to our understanding of the interaction between diet, disease, environment and culture in ancient human populations. Stable isotopes have been used to supplement and enhance historical, archaeological, bioarchaeological, zooarchaeological, and archeobotanical information related to a variety of paradigms that focus on the behavior of humans their complex interrelationships with their surrounding world. Prior to the inclusion of this type of analysis much of the inferences made regarding many of these fields were based on the analysis of artifacts, faunal material, and skeletal morphology. These standard types of analyses for archaeological and

bioarchaeological research have shouldered much research burden and have been more than adequate. The addition, however, of bone chemistry in the form of isotopic analysis allowed scientists to make statements that were more accurate regarding population shifts in diet, cultural behaviors (weaning and migration), and exploitation of resources even when archaeological evidence for the behaviors (faunal/floral, artifacts, etc…) were not readily available for analysis.

Early research into the archaeological applications and the proposition that stable isotopes (carbon) could be used for identifying ancient diet, was based on findings by Hall (1967) in which anomalous ^{14}C dates, in addition to elevated $\delta^{13}C$ values, were identified in maize (C_4 plant) in comparison to non-C_4 plants. These findings, specifically in relationship to stable isotopes (carbon), were subsequently validated by Vogel and Van Der Merwe (1977) on an archaeological Native American population from New York. The different photosynthetic pathways (C_4 vs C_3) were identified as the foundation for the differences in the $\delta^{13}C$ ratios in the New York population. From these early studies into the use of stable isotopes in archaeology as well as other reviewed by Ambrose and Krigbaum (2003) and Katzenberg (2008) the field of isotopic bone chemistry has become a standard method incorporated into bioarchaeological research.

In addition to early studies on carbon (and nitrogen) isotopes and its application to identifying diet, a variety of other stable isotopes have been utilized for answering questions related to past human behavior within bioarchaeology. Strontium has been used to trace human migration and identify communities with in larger populations (Price et al., 2000). Similarly, (Dupras, T. L., & Schwarcz, 2001) used oxygen isotopes ($\delta\ ^{18}O$) to identify movement of people. More detailed

review of the use of different stable isotopes as applied to archaeology and bioarchaeology can be found elsewhere (Katzenberg, 2008; Ambrose and Krigbaum, 2003; Sealy, 2000).

The majority of research in bioarchaeology that incorporates stable isotope analysis primarily focuses on carbon and nitrogen (see below) to answer questions related to past human diet. Additionally, in association with dietary inferences, these isotopes have also been utilized to make statements regarding migration (Richards et al., 1998; Pollard et al., 2011) and cultural practices (ex. weaning) (Dupras and Tocheri, 2007; Fuller et al. 2006; Prowse et al., 2008) as well as to supplement statements regarding climate. The analysis of stable isotopes in bone and teeth offer powerful supplemental data that can greatly enhance our understanding human culture in archaeological populations.

A major trend in the use of isotopes in archaeology and bioarchaeology has been to formulate population centered questions as can be found with most recent publications. This is probably, in part, a result of the current direction of the field bioarchaeology, which has shown a shift away from a case-study focus in favor of population approach. This change, while necessary and invaluable to understanding the larger picture, often blurs the individual out of the picture.

It is noted, however, that it is not the intention here, to suggest that stable isotopes use in archaeology is anything other than another set of data that can and does add significantly to our understanding of past human behavior and that it should be used as a supplement to archaeological (includes all sub-fields) data were applicable.

Principals of Carbon and Nitrogen Isotopes

This section is meant to give a brief background into the foundation and principles of stable isotopes and only includes minimal technical information. For a more detailed discussion see Katzenberg (2008) and Sealy (2000). Moreover, this review will only include information regarding carbon and nitrogen as these are the only stable isotopes utilized for this dissertation. Acceptable C/N ratios used for this dissertation was between 2.9 and 3.6 following DeNiro (1985).

Stable Carbon Isotopes

Atmospheric CO_2, which is the source of carbon dioxide for all terrestrial plants, is found naturally in two stable forms, ^{12}C and the heavier ^{13}C. The difference between these two isotopes has to do with the variation in the number of neutrons, as the number of protons remains the same. The differences in the atomic mass lead to the differential discrimination between the lighter and heavier isotope during photosynthesis. Stable carbon isotopes are largely represent the protein portion of the diet and, in terms of dietary reconstruction are primarily used to differentiate between C_4 and C_3 based diets in addition to distinguishing between marine and terrestrial based diets (Katzenberg 2008; Sealy, 2000; Craig et al., 2009).

During the process photosynthesis, terrestrial plants convert CO_2 into glucose via one of two major pathways; Calvin – Benson (CB) or Hatch – Slack (HS). One of the defining characteristics of these pathways is the extent to which plants discriminate against the heavier of the two stable carbon isotopes (^{13}C). Plants using the HS (C_4 plants) method of photosynthesis will discriminate less against ^{13}C leading to less negative (more enriched) values. Alternately, C_3

plants (those using the Calvin – Benson pathway) discriminate more against ^{13}C (Sealy, 2000) leading to more negative values (less enriched). These differences in the photosynthetic routes for CO_2 conversion leads to variation in ratio of ^{12}C to ^{13}C in the tissues of different plants, a process called 'fractionation', as compared to the international standard, Vienna Pee Dee Belemnite (VPDB) (Katzenberg 2008). Tracking and understanding the process of fractionation through the food web, which includes humans, is the basis for applying stable carbon analysis as a resource for understanding a variety of aspects of ancient human behavior. A third photosynthetic pathway, Crassulacean Acid Metabolism (CAM) is used by plants, the majority of which are succulents and cacti, which have the ability to alternate between CB and HS pathways (Larsen 1997; Vogel and Van Der Merwe 1977). This particular group of plants is likely not to have been part of the diet of Roman Sirmium and therefore will not be discussed further.

The majority of plants, including a variety of cereals (wheat and barley), that grow in temperate regions of the globe are C_3 plants fixing CO_2 via the CB pathway. The tissue of these plants, through fractionation, yield $\delta\ ^{13}C$ values that range between -20‰ and -36‰ (Katzenberg 2008; Sealy 2000; Vogel and Van Der Merwe 1977). C_4 plants, on the other hand, which consist of mainly tropical grasses, maize, millet and sorghum exhibit more enriched $\delta\ ^{13}C$ values with a range that falls between -8‰ and -14‰ (Sealy 2000). Consumers of these plants show an approximate shift of 5‰ in addition to 1‰ trophic level effect $\delta\ ^{13}C$ for the collagen portion of bone, as compared to their diet (Schwarcz and Schoeninger, 2011). As noted by Kilgrow (2010) and Katzenberg (2008) a key factor as in distinguishing between these pathways, and thereby

being able to utilize carbon isotopes for identifying dietary trends in archaeological human populations, is the lack of overlap between these two photosynthetic pathways.

Taking in consideration fractionation and the trophic level effect observed in stable carbon isotopes, humans that consume a diet composed of protein from a C_3 pathway, should exhibit $\delta^{13}C$ values of collagen that are in the area of -20‰ (Keenleyside et al., 2009). Alternatively, individuals with a diet that targets protein that reflects a C_4 pathway should exhibit $\delta^{13}C$ collagen values of approximately -10‰. The addition of marine based should lead to enrichment of $\delta\ ^{13}C$ values (Chishom et al., 1982).

Stable Nitrogen Isotopes

Like carbon, nitrogen has two stable isotopes; ^{14}N and ^{15}N. The majority of nitrogen is in the form of N_2 and can be found either in the oceans or as part of the atmosphere (Larson, 1997). Nitrogen isotopic analysis is based on the calculation of the ratio of ^{14}N to ^{15}N, within a given sample, as compare to an international standard (AIR) and an understanding the 'trophic' position of an organism within the relative food web. Atmospheric nitrogen (N_2) has a value of approximately 0‰ (Sealy, 2000). Occupying the base of the food web in regards to plants are legumes, which include a variety beans, have nitrogen values that are close to atmospheric nitrogen (0‰) while many of the non-legumous plants have ^{15}N values that range between 1‰-5‰. Herbivores, which occupy the trophic level above the plants they consume, are enriched in $\delta^{15}N$ by approximately 2-3‰. This 2-3‰ increase in $\delta^{15}N$ is also observed in human collagen as compared to the diet they consume. The trophic level effect, or the stepwise enrichment, observed moving up the food chain is the foundation for the use of stable nitrogen isotopes for

paleodietary reconstruction (Katzenberg, 2008). Stable nitrogen isotopes are primarily used to identify the difference between the protein portion of marine and terrestrial based diets. The consumption of marine based food will lead to enrichment of bone collagen in human in the range of 12-22‰, while a terrestrial based diet should lead to ^{15}N values in the neighborhood of 5-12‰ (Schoeninger and DeNiro 1984). Additionally, nitrogen isotopes have been successfully used to identify individuals that were breast-feeding/weaning, which is based on the same principle of the trophic level effect. Infants and children that are nursing are essentially feeding on the mother's tissue (breast milk) and therefore should occupy one trophic level (2-3‰) above females.

There are a number of variables that can and do influence the enrichment or depletion ^{15}N and ^{13}C values of both plant and animal tissues beyond the expected differences caused CO_2 pathways and or trophic levels. As discussed by van Klinken et al. (2002), the ^{13}C values for C_3 plants show differences depending on the climate of the region. This, according the Richards and Mellars (1998), translates into an enrichment of approximately 1-2‰ ^{13}C in the collagen of bone for human in warmer climates as compared to individuals from colder European regions. Climate can also influence ^{15}N values in animals. Water stress (lack of H20) can lead to more enriched ^{15}N values and therefore, might incorrectly suggest that the human, being one trophic level above the animal being consumed, was incorporating, at least in part, some marine protein. The consequences of 'water stress' and its record in the isotopic values are normally found in arid and hot regions. In addition to variables mentioned here, Malainey (2011) summarizes a more in depth list of potential factors that cause variation in ^{13}C and ^{15}N values. These potential factors

will be taken into consideration, were applicable when interpreting the isotopic data especially when making comparisons between similar temporally related but of different climatic regions. Disease (protein deficiency) could affect isotopic values, effectively elevating nitrogen values as the body begins to consume itself (Katzenberg 2008). This factor would be especially important to consider when selecting specific bones and when interpreting the isotopic results of individual that exhibit pathology.

Diet and Isotopes

Food is essential for life. Modern human is diet is the result of a complex interaction between, at very superficial level, the natural environment, individual metabolic requirement, and cultural rules. At the most basic level, food is required for basic physiological processes, health and growth and development. As discussed previously (see Chapter 5), a poor diet lacking in essential nutrients, has a synergistic relationship with increase in physiological stress and pathological conditions. Individuals most susceptible to nutrient diseases and malnutrition were infants and children still actively growing (Danforth 1999). Both bioarchaeological and clinical studies have clearly shown there is a link between poor diet and a number of identifiable stressors in the human skeleton (Larsen 1997).

Baring the physiological requirement, human diet is based on two general variables; the environment and culture. The defining line, however, between the natural origin of the food resource and the cultural rules that govern its use are often blurred as variables from each category effectively cross this seemly clear boundary. Cultural rules play a significant role in the access and distribution of food in ancient societies, as they do in modern populations, clouding

what would seem to be a relatively simple need based relationship with food. Food in during the Roman Empire was subjected to the same complexities as today.

Roman Diet

According to period authors (see Galen, Soranous, etc…), Roman diet consisted mainly of cereals, olives and wine with additions of some meat and fish. Much of this information applies to upper class Roman citizens and generally focuses on the Italy and the eastern Mediterranean (Keenleyside et al 2009) and may not necessary reflect the diet of the majority of people living within the Roman Empire. Moreover, the vastness of the Empire geographically and environmentally and the extensive cultural variation are two general factors that are likely to have played a significant role in make-up of diet. This taken in to consideration, much of the writings suggests that the Roman diet was largely based on a 'Mediterranean Triad' which consisted of mainly a variety of cereals (wheat and barley), olives, and wine (Garnsey 1999). The extent that wild foods played a role is not completely understood but some suggests that it may have played a significant role (Kilgrow 2010).

Grains

Wheat (various species) followed by barley formed main grains consumed as part of the Roman diet. Other cereals, including oats, rye and millet were also part, although to a lesser extent, of the cereal based diet of Roman period. According to Galen,, oats which were produced during the Roman Period were considered, under normal conditions, to be for the use of animal fodder or during times of famine. As noted above, millet, in its various forms, was consumed by humans, but has been, by many modern authors (Spurr 1983; Prowse 2001), been relinquished to

a similar fate as that of oats, animal fodder or famine food. Writings by Galen and Cassius Dio do depict as a 'lesser' grain to be used for human consumption during dire times.

Cereals as a group were considered to the central piece for Roman diet. The proportion of type of grains utilized for dietary consumption within a given population is difficult to discern as most of the historical period writing focus on the 'ideal' diet of the upper class of Rome. Access to the primary grain, wheat, was in part related to economics which would thereby restrict the people of lower economic from access to this particular cereal grain. As most modern and historical authors note, lesser grains, (eg. millet) were used primarily during periods of food shortage and or as animal fodder but according to **(**Spurr 1983**)** they were probably utilized on a more regular basis by the poor and by specific sub-groups (infants) as a supplement during the weaning process. In addition to the potential bias for the distribution within a population, most of the data regarding diet currently used as reference for Roman diet is based largely dietary evidence from Italy with less information available from other provinces (i.e. Pannonia).

Animals

Evidence from zooarchaeological remains and from historical writing, suggests that animal flesh and their by-products, both domestic and to a lesser extent wild, played a smaller role in the Roman diet in comparison to cereals which, according to Garnsey (1999) are thought to comprise approximately 75% of the total dietary intake. Similar to that of cereals, there was a hierarchy in regards to the types of meat and their significance in Roman diet. Evidence from archaeological sites in Italy and elsewhere supplement in historical writings that suggest that pork was the primary meat being consumed (Prowse et al. 2004) by the majority of the

population. Sheep, goats, and cows were mainly used for secondary products (ie wool) or as draft animals and to a lesser extent for human consumption. Social and economic class did play a significant role in the access to animal food sources. While individuals that were part of the upper class did have more access to meat and did in fact consume more meat, it does not seem to have comprised a significant proportion of their diet (Garnsey 1999).

In addition of differences the quantity of meat consumption between economic classes, there is some evidence to suggest that dietary inclusion of meat differed according to occupation. Dietary regime of military has been found to have included significant meat consumption above that of the population as a whole. Similar to the main body of the population, however, pork again is thought to have been the main type of meat consumed by the army (Garnsey 1999). Regional differences, however, have been identified. Zooarchaeological evidence from Britain (Redfern et al 2010) and the Danubian Region (Bökönyi 1984) suggest that military diet in these specific regions included a wider variety of meat, which included oxen, fowl, and some wild fauna (deer). Further distinction in the access to meat is also hypothesized to have occurred both according to sex and at the level of the family unit with females and children have reduced access to meat (Garnsey 1999).

Marine and Fresh Water Resources (Fish)

At the apex of the Roman Empire (2nd Century CE) the provinces controlled by Rome bordered (in some part) all sides of the Mediterranean with some regions (i.e. Britain) having coastal borders on the Atlantic and thus it would be expected that the populations occupying these regions would incorporate marine resources into their diet. In addition to the many marine

coastal sites, Roman settlements often bordered or were in close proximity to major bodies of fresh water, which included lakes and rivers (i.e Sirmium). Similar to marine coast population, the inclusion of fish into the diet of ancient Romans living in the vicinity to fresh water would be expected. Based on historical writings, archaeological evidence and Roman period cookbooks fish (marine and fresh water) was consumed in a variety of forms including but not limited to salted and in the form of fish sauces (i.e garum). Again, similar to both cereals (wheat) and meat, access to fish (fresh and marine based) as a dietary resource was to some extent based on economic standing. While it is noted that fish was not a necessarily a significant segment of Roman diet, whether due to it being a luxury item (Prowse et al. 2004; Garnsey 1999) or for the potential risk involved with fishing (Keenleyside et al. 2009), evidence from some coastal and non-coastal sites suggest that fish played a significant dietary role (Craig, 2009). In addition, while not making any assumption on the quantity of proportion to the overall diet, Galen writing in the 2nd century AD (Grant 2002) discusses many of the fish species that were consumed by ancient Romans both from the sea and from riverine environments.

Further divisions regarding fish consumption might be found along male/female lines, specifically regarding the consumption of fresh water fish. Rufus of Ephesus, writing in the 1st century AD, suggests that females should not consume specific types of fish which he based on the 'balancing of the humours'. In addition the placement of males within Roman society also had the potential to play a role in the limiting of access to marine and fresh water resources (fish) for females. The extent to which these suggestions regarding restricting female consumption of fish were followed is likely to be correlated with geographic region, accessibility and local cultural practices (see Keenleyside et al 2009 and Craig et al. 2009).

Roman Diet – Pannonia

Evidence for diet for the Roman Period in Pannonia is sparse. Historical records (Soproni 1980), artifactual remains (Eadie 1971) and floral and faunal material from archaeological sites verify the presence of specific domesticates. Zooarchaeological remains from Imperial Roman Age Pannonia show evidence of domesticates such as ox, sheep, goat and pig as well as minimal amounts of fish bone (Bökönyi 1984; Fitz 1980). In addition, paleobotanical remains from this region and time period have also been recovered including material from the main agricultural crops, wheat, barley, and rye (Fitz 1980) and to a lesser extent millet (Ransborg 1991).

Roman Sirmium - Diet

Standard macroscopic analysis of zooarchaeological and or paleobotanial material to date, not been completed. The few scattered remains of animal bones and agricultural implements found during archaeological excavations in Sirmium paint an incomplete picture of food consumption.

Sirmium - Zooarchaeological Material

No zooarchaeological research relating to the Roman Period in Sirmium has been conducted. This is largely a consequence of the focus of the archaeological exaction between 1968 -1973. During these five years the primary goals of the project was to determine the layout of the town and the excavation of the St. Sineros cemetery.. While a small amount of faunal material from the cemetery area was recovered, the lack of a large sample from a secure context puts significant limitations on the statements that can be made regarding the diet of the Roman Sirmium between the 1st and 6th Century AD. Furthermore, cemetery zooarchaeological material is likely not to be representative of the overall diet of individuals from Sirmium, as burial ritual

would often regulate specific types of food material being deposited, therefor creating a biased sample of recovered fauna.

As mentioned above, a small amount of faunal material from Locality 26 was recovered during excavations in 1970, primarily from Sounding 12A (see Figure 3.3). Mixed in with the collected animal bone were some fragments of human bone. The majority of this zooarchaeological material consists of Large and Medium Terrestrial Mammals (LTM and MTM) and was not associated with a specific grave. According to the original grave and burial descriptions, there were occasions in which faunal material was recorded as being found within some of the graves. Unfortunately, the notes do not differentiate between material found in the fill of the grave or that which was directly associated with the skeletal material. Furthermore, photographs taken after skeletons were exposed do not visually or in the associated descriptions indicate the presence of faunal material.

Paleodiet Reconstruction

Standard reconstruction of human diet includes data compiled from zooarchaeological, archaeobotonical and archaeological data sets. These areas of research offer the basis for human dietary reconstruction as should be applied whenever applicable. The floral and faunal material recovered form archaeological sites represent human manipulation of these biological resources and under most circumstances are likely to indicate part of the human dietary sources of a given population. Zooarchaeological material will not, however, directly identify the consumer; it will instead indicate that a specific animal resource was used. Furthermore, both quantitative and qualitative analyses of faunal material will not necessary illuminate the extent to which a specific

animal species or group of species were being utilized as a food source for a population (Larsen 2002). This issue was further pressed by Katzenberg (2008), noting that zooarchaeological material will not specifically identify the individual that consumed specific food types and or answer questions regarding dietary inequalities related sex, age group or social class. As noted earlier, culture plays a significant role in controlling potential diet as well as the access to food resources by individuals/groups within a population. Here, the use of dietary isotopic analysis will aid in unraveling of the complexity of human diet the cultural practices governing it.

The use of dietary isotopes, specifically carbon and nitrogen, has been successfully applied to archaeological populations spanning a broad temporal and spatial framework. As discussed above the fractionation of carbon and the trophic level effect of nitrogen moving through the food web provide much of the foundation for the use of isotopic analysis for paleodiet studies.

The Specific Isotopes Used This Dissertation and Expectations

Using the collagen portion of bone, this dissertation will employ stable carbon and nitrogen isotopes analysis to address questions regarding diet, cultural practices (weaning), and disease in a sub-sample of individuals from Roman Imperial Sirmium. It will attempt, at the individual level, to differentiate between the consumption of C_3 and C_4 plants, in addition to identifying possible marine (fish) consumption. From a dietary standpoint, the results from these analyses will be compared to the ideal 'Roman Diet' (see above), which according to Garnsey (1999) mainly consisted of cereals, olives, and a small amount of meat. In addition, the potential for dietary incorporation of riverine resources (fresh water fish) will also be considered specifically because of Sirmium's geographic position on the bank of the Sava River.

Inferences are made in relation to migration, climate and health and disease based on the isotopic work conducted for this dissertation, but the majority of the focus is related to diet and the process of weaning and its relationship to the life histories of the non-adult sample. Below is a review of the archeological use of the two isotopes used in this dissertation. It offers only a basic background in the theoretical foundation and practicality for the use of carbon and nitrogen isotopic analysis for paleodiet research.

Isotope Expectations

Isotopic expectations for the Sirmium sample are discussed below. Unfortunately, due to a lack of zooarchaeological material from Sirmium comparisons will be made to the carbon and nitrogen values of collagen obtained from other archaeological faunal material. An attempt will be made to use data that most closely resembles material recovered from similar climatic regions as it known that temperature does cause small shifts in both carbon and nitrogen values for C_3 plants. Statements made regarding expectations therefore must be viewed with caution.

Breastfeeding/Weaning

Based on historical writers of the time period (Galen and Soranus) and the current understanding of isotopic research on weaning during the Roman Period, it would be expected that individuals would show some evidence of incorporation of non-breast milk into their diet as early as 6 months. With increasing amount of solid food a complete cessation of breast milk should be observed between the ages of 2 and 3. Breastfed individuals should exhibit enriched $\delta^{15}N$ levels between 2‰-3‰ above adult females (or one trophic level). In addition, there should also be ~1‰ enrichment in $\delta\ ^{13}C$ above the adult females as compared to infants and children that are

actively breastfeeding (Katzenberg, 2008). Scaling of both nitrogen and carbon values would also be expected as children are being subsequently weaned. Therefore, $\delta^{15}N$ values should become more depleted with increasing in age as coordinated correlated with a decrease in breast milk and an increase in weaning foods. The shift in $\delta^{13}C$ from breastfeeding values to closer to that of the female average is thought to occur faster in comparison to $\delta^{15}N$ which would indicate the inclusion of non-breast milk supplement foods (Fuller et al., 2006).

Post-Weaning Diet

Garnsey (1999) and others as noted earlier have suggested that there was a basic Roman diet which was heavy on cereals, olives and wine. Addition of meat and fish were in some cases only a small part of the diet, but under certain circumstances could comprise as significant proportion of the diet (see Keenleyside et al., 2009). In relation to Sirmium's close proximity to the Sava River, I would expect that there would some dietary incorporation, which depending on the trophic level of the fish would lead to more enriched $\delta^{13}C$ and $\delta^{15}N$. Alternatively, more depleted $\delta^{13}C$, in the assumed range of terrestrial herbivores, with elevated $\delta^{15}N$ values could also be expected if the fish being consumed occupied a lower trophic level. If individuals at Sirmium were consuming a diet that consisted mainly of food with a C_3 origin, it would be expected that the $\delta^{13}C$ and $\delta^{15}N$ should exhibit a trophic level shift of approximately 1‰ and 2-3‰, respectively above the animals consumed. As noted earlier, the use millet (C_4 plant) was cultivated in Pannonia during the Late Roman Period and therefore could have been consumed directly by individuals from Sirmium or indirectly through animal feeding on millet based fodder. If millet was directly and or indirectly consumed, enriched $\delta^{13}C$ values with the depleted $\delta^{15}N$ values would be expected (Bonsall et al., 2004).

Isotopic studies have identified evidence for differential access to food types (i.e. meat) based on age and sex, in addition to economic status, during the Roman period. As such it would be expected that males (adult), having greater access to meat (and fish) based on their position within society, would have more enriched $\delta^{13}C$ and $\delta^{15}N$ values as compared to adult females (Keenleyside et al., 2009).

Isotopic Methods

All isotopic samples were processed at Scottish Universities Environmental Research Centre (SUERC) under the direction of Dr Gordon Cook. Preparation, the including removing the sub-samples of bone for analysis was conducted at SUERC, as no such laboratory is available at Brooklyn College. For a detailed description of the sample preparation and the analysis including specifics regarding laboratory equipment see Appendix C.

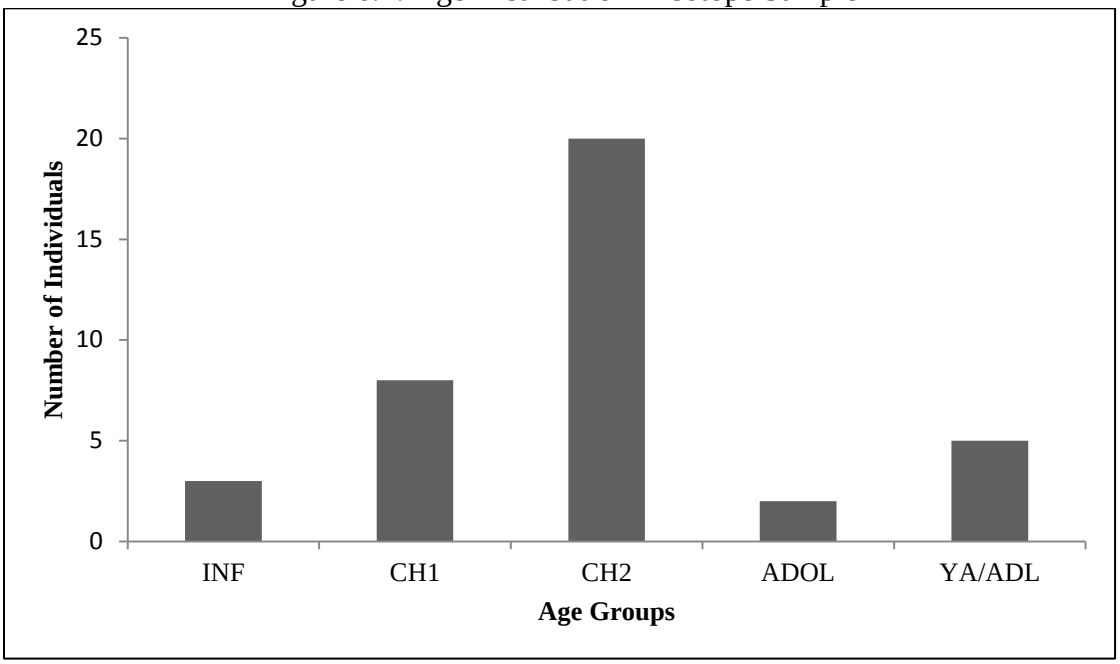
Sample Selection

Bone samples from thirty-nine individuals from Local 26 ranging in age from 3 weeks to 44 years old (see Figure 6.1) were selected to undergo stable carbon and nitrogen isotopic analysis using the collagen portion of bone. As infant and child dietary patterns (including weaning) were primary goals of the isotopic analysis, the majority of individuals sampled were between 0 and 14 years of age (n=31). The remaining eight individuals comprised a mixture of adolescents (15-17 years of age) and young adults/adults (18-44 years of age). All eight non-infant/child individual were subjected to sex determination. Of these, six could be sexed, with three individuals identified as males and three exhibiting female characteristics. While the sample of females is small and might not reflect the diet of females from Sirmium, the inclusion of the few

identified females was nonetheless considered to be important as they are needed to facilitate the basis for comparison of the isotopic values of individuals of weaning age.

Due to incompleteness of the skeletons, a standardization of bone selection could not be achieved. Selection of bone was therefore, based on presence of the element and the overall preservation (see Appendix C for list of bones used). In addition, archaeological contextual information and evidence of pathology was also considered during selection. For individuals with evidence of bone pathology, instructions to avoid, when possible, pathological regions, as they have been shown to give different isotopic values compared normal bone from the same skeletal element of an individual (Katzenberg and Lovell, 1999).

Figure 6.1: Age Distribution – Isotope Sample



Key: INF=Infant (0-1 yrs.); CH1=Child 1 (1-5 yrs.); CH2=Child 2 (6-14 yrs.); ADOL=Adolescent (15-17 yrs.); YA/ADL=Young Adult/Adult (18-45 yrs.)

6.2 Results

All 39 individuals submitted for isotopic analysis returned both $\delta^{13}C$ and $\delta^{15}N$ isotopic values which are presented in Table 6.1 and Figure 6.2 and 6.3. Of these, only one sample (BCL269N-EXT-3), an adolescent returned a C/N ratio (MOL=4.7) outside the acceptable range of 2.9-3.6. While the $\delta^{13}C$ and $\delta^{15}N$ values for this individual (-19.7/10.1, respectively) fell within the range of all samples, it was nonetheless removed from all further statistical analysis. $\delta^{13}C$ values for the entire sample were shown to have an average of -18.83‰ (-20.3‰ to -16.2‰) and a standard deviation (SD) of .97. A significantly larger difference was found between enriched and depleted $\delta^{15}N$ values with a range of 6.8‰-13.9‰ (AVG=10.36‰) and a SD of 1.4.

Table 6.1 : Sirmium $\delta^{13}C$ and $\delta^{15}N15$ Isotopic Results for Bone Collagen

BCINV	Sex ID	AGE	AGE GROUP	SUB-GROUP (CHILD)	$\delta^{13}C$	$\delta^{15}N$	MOL
10M-10	NA	0.08	INF	NOT APPL	-19.6	11.1	3.30
12-QUAD 6-1	NA	0.13	INF	NOT APPL	-18.7	12.9	3.40
10H-2	NA	0.5	INF	NOT APPL	-18.6	12.7	3.30
8N-1	NA	1	CH1	G1	-16.9	12.8	3.30
12AE-EXT-1	NA	1.19	CH1	G1	-18.5	13.9	3.40
10M-1	NA	1.5	CH1	G1	-19.4	10.7	3.30
11J-5	NA	1.75	CH1	G1	-18.8	12.1	3.40
11N-EXT-1	NA	2.5	CH1	G1	-19.4	10.0	3.40
10C-1	NA	2.67	CH1	G1	-18.8	11.9	3.50
12A-1	NA	3.38	CH1	G2	-20.2	9.9	3.30
12ASW-QUAD-1	NA	4.7	CH1	G2	-19.9	9.8	3.30
12ANW-QUAD-1	NA	6	CH2	G2	-19.1	10.4	3.20
7F-1	NA	6.2	CH2	G2	-16.9	9.3	3.40
10M-5	NA	6.25	CH2	G2	-18.7	9.5	3.20
7G-1	NA	6.49	CH2	G2	-16.2	9.9	3.40
12ANW-QUAD-2	NA	6.75	CH2	G2	-19.3	8.3	3.50
11EF-EXT-1	NA	6.76	CH2	G2	-18.6	9.8	3.20
8J-1	NA	7	CH2	G2	-19.0	9.2	3.20
10M-6	NA	7.03	CH2	G2	-18.5	9.9	3.20
10C-2	NA	7.24	CH2	G2	-19.2	9.8	3.50
11M-1	NA	7.75	CH2	G2	-16.5	12.3	3.40
12AE-EXT-3	NA	9	CH2	G3	-19.5	6.8	3.50
9N-EXT-2	NA	9	CH2	G3	-17.5	10.1	3.50
11J-1	NA	9.28	CH2	G3	-18.6	10.4	3.10
12AE-EXT-5	NA	11.3	CH2	G3	-20.3	9.3	3.30
12ASW-QUAD-2	NA	11.3	CH2	G3	-18.3	10.6	3.30
11F-1	NA	11.8	CH2	G3	-19.7	10.0	3.30
10M-8	NA	12	CH2	G3	-18.4	10.3	3.30
11N-1	NA	12	CH2	G3	-19.5	10.3	3.30
5K-1	NA	12.5	CH2	G3	-19.0	10.6	3.30
8F-1	NA	13.8	CH2	G3	-20.2	8.2	3.30
10H-1	NA	16	ADOL	NOT APPL	-18.9	10.2	3.40
7F-3	F	16.1	ADOL	NOT APPL	-19.3	9.5	3.20
9N-EXT-3*	NA	16.1	ADOL	NOT APPL	-19.7	10.1	4.70
8L-2	F	22.5	YA	NOT APPL	-19.8	9.7	3.30
8M-1	F	24.3	YA	NOT APPL	-19.6	11.6	3.40
2H-2	M	37.2	ADL	NOT APPL	-18.6	10.6	3.40
9N-EXT-8	M	41.1	ADL	NOT APPL	-18.5	10.1	3.40
3G-5	M	44	ADL	NOT APPL	-19.0	9.0	3.40
AVERAGE					-18.83	10.36	
SD					.97	1.40	

All Delta Values are in Per Mil (‰)

Figure 6.2 – δ ^{13}C Values – All Ages

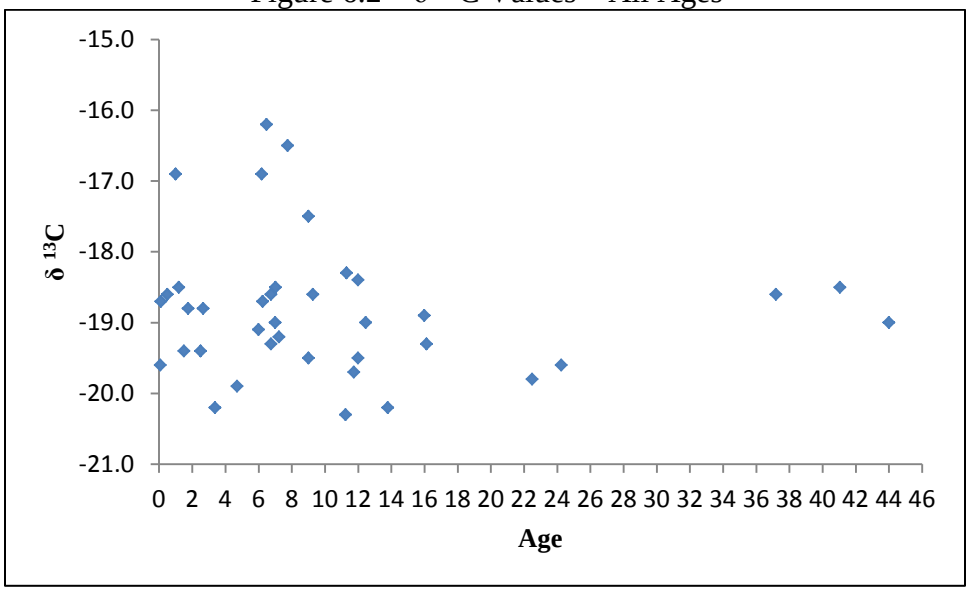
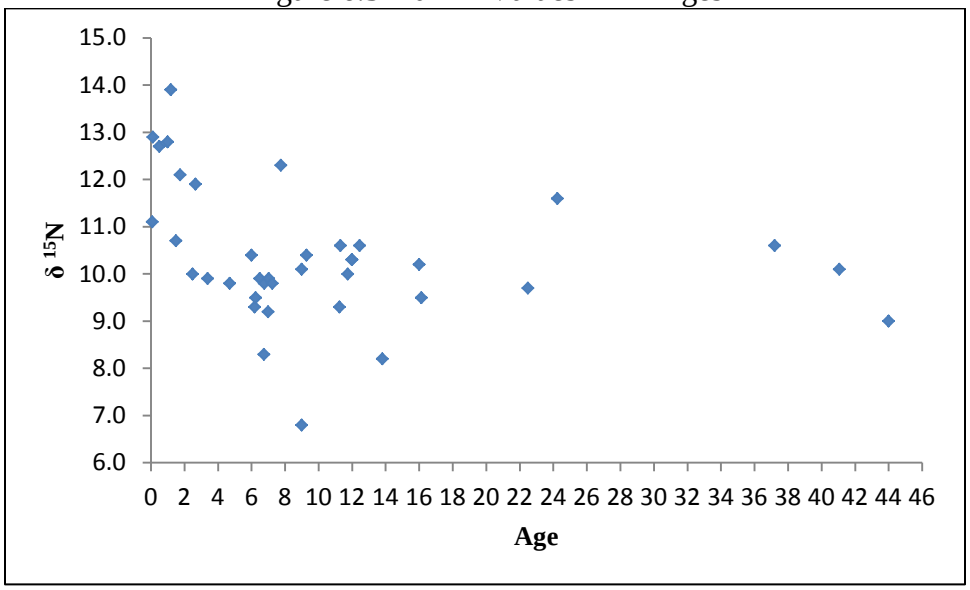


Figure 6.3 – δ ^{15}N Values – All Ages



Clear distinctions were found between carbon and nitrogen values of infants/children of weaning age and individuals of post-weaning age. Further distinctions were identified within the subgroup of post-weaning aged children, with older individuals showing more enriched nitrogen values as compared to younger children. Non-child/infants showed less variation in the isotopic values as compared to both weaning and post-weaning children. Five post-weaning aged children were

identified as outliers, having $\delta^{13}C$ and or $\delta^{15}N$ values that were considered to be significantly enriched and or depleted as compared to average isotopic values for this subgroup.

As will be discussed in more detail below, the overall average for all individual for $\delta^{13}C$ is slightly more enriched than would be expected for a diet based on C_3 food. The removal of individuals with abnormally enriched $\delta^{13}C$ values in addition to those infants and children still breast-feeding and or weaning there is shift the $\delta^{13}C$ average to -19.19‰ which is more in line with diet consisting mainly of C_3 terrestrial based diet. Similarly, after removing individual of breast-feeding age the N15 also decreases to a level more consistent with terrestrial based protein. Therefore, in discussing overall diet a distinction must be made between age groups, specifically pre-and post-breast feeding groups. In the following sections I will briefly discuss the results of the individual subgroups according to age.

Infants

Infants comprised a small segment (n=3) of the overall isotopic sample tested. The $\delta^{13}C$ ranged from -18.6‰ to -19.6‰ (see Table 6.2) with a mean value of -18.97 ‰ and a standard deviation of .55. $\delta^{15}N$ values had a range of 11.1‰ to 12.9‰, with an average of 12.23‰ and a standard deviation of .99. All three of the individuals from the sub-group showed evidence of some enrichment of N15 above the female average. Following this pattern of enrichment, 2 of the 3 infants also exhibited C13 values that are more positive than the female average. More specifically, SL2610M-10, aged three weeks, had the most depleted carbon value at -19.6‰ with only slight evidence of $\delta^{15}N$ enrichment (11.1‰). The remaining two infants both exhibited evidence for enriched $\delta^{13}C$ and $\delta^{15}N$.

Table 6.2: Sirmium $\delta^{13}C$ and $\delta^{15}N15$ Isotopic Results - Infants

BCINV	Sex ID	AGE	AGE GROUP	SUB-GROUP (CHILD)	$\delta^{13}C$	$\delta^{15}N$	MOL
10M-10	NA	0.08	INF	NOT APPL	-19.6	11.1	3.30
12-QUAD 6-1	NA	0.13	INF	NOT APPL	-18.7	12.9	3.40
10H-2	NA	0.5	INF	NOT APPL	-18.6	12.7	3.30
AVERAGE					-18.97	12.23	
SD					.55	.99	

All Delta Values are in Per Mil (‰)

Children

Bone samples from 28 children (1-14 years of age), representing 73.7% of the total sample of individuals analyzed for dietary isotopes, were subjected to stable carbon and nitrogen isotopic analysis (see Table 6.3). Of these children, eight individuals or 28.57% were between 1 and 5 years of age (CH1) with the remaining 20 children (71.43%) falling into the age range of 6 through 14 years old (CH2). Six of the twenty-eight children (21.43%) represented individuals that were still of weaning age (up to 3 but not over 3yrs of age) which consequently made up 75% of the CH1 group (or 6/8) with the remaining post-weaning age children constituting 78.57% (n=22).

Carbon and Nitrogen values exhibited considerable variation across all child age groups which are likely to have been influenced by cultural shifts in behavior (breastfeeding), change in diet (introduction of weaning foods, consumption of marine foods, etc…), and access to food resources and possibly disease. $\delta^{13}C$ were shown to have an elevated value of -16.2‰ and a low (depleted) of -20.3‰, a difference of -4.1‰, while $\delta^{15}N$ values fell between 13.9‰ and 6.8‰, with a difference of 7.1‰. The average value for $\delta^{13}C$ was -18.75‰ with a standard deviation of 1.09. $\delta^{15}N$ values had an average of 10.22‰ and a standard deviation of 1.43. It should be noted that that the averages and the standard deviations mentioned above take into consideration all values, including potential outliers. There is a significant difference standard deviation for $\delta^{13}C$

when the specific outliers are removed; shift from 1.09 to .6035 which suggests a greater clustering of values. Calculations regarding specific sub-topic with the isotope analysis will discuss these deviations further.

Evaluation N15 values of the child cohort exposed three cluster patterns (see Table 6.3 and Figure 6.3 and 6.5) that seemed to be correlated with a specific age range. Based on isotopic values for N15, child sub-group 1 (G1) are aged between 1-2.67 years, G2 were aged between 3.38 and 7.75 years, and the last group (G3) consists of the remaining children (9-13.8 years old). Individuals from G1 with an average of δ^{15}N 11.9‰ exhibited the most elevated values as compared to G2 and G3. The majority of children from G1 had N15 levels between 11.9‰ and 13.9‰ showing similarly enriched values as was observed in the infant cohort. G2 individuals generally exhibited depleted N15 values with the majority falling in the range of between 9.3‰ and 9.9‰ of N15. The majority of children associated with G3, have N15 values that range between 10.0‰ and 10.6‰. While trends did emerge, as was expected, there were individuals from each of the three groups that did not follow the patterns associated with the specific age ranges.

Cluster patterns related to C13 values similar to those identified with N15 values were not identified. Evidence for both enriched and depleted C13 levels was found in all sub-groups of children. No clear trends could be identified with regards to shifts in age. It was, however, apparent that some grouping, not in line with age, was associated with C13 values. The majority of children, consisting of individuals between the ages of 1 and 12.5, had C13 values between -18.2‰ and -19.5‰ (n=18). Five children with C13 values more enriched (-17.5‰ to -16.2‰)

were represented by individuals between 1 and 9. The remaining children (n=5) showed the most depleted values (-19.7‰ to -20.3‰) and had an age range between 3.38 and 13.8 years old.

Table 6.3: Sirmium $\delta^{13}C$ and $\delta^{15}N$ Isotopic Results - Children

BCINV	Sex ID	AGE	AGE GROUP	SUB-GROUP (CHILD)	δ ^{13}C	δ ^{15}N	MOL
8N-1	NA	1	CH1	G1	-16.9	12.8	3.30
12AE-EXT-1	NA	1.19	CH1	G1	-18.5	13.9	3.40
10M-1	NA	1.5	CH1	G1	-19.4	10.7	3.30
11J-5	NA	1.75	CH1	G1	-18.8	12.1	3.40
11N-EXT-1	NA	2.5	CH1	G1	-19.4	10.0	3.40
10C-1	NA	2.67	CH1	G1	-18.8	11.9	3.50
12A-1	NA	3.38	CH1	G2	-20.2	9.9	3.30
12ASW-QUAD-1	NA	4.7	CH1	G2	-19.9	9.8	3.30
12ANW-QUAD-1	NA	6	CH2	G2	-19.1	10.4	3.20
7F-1	NA	6.2	CH2	G2	-16.9	9.3	3.40
10M-5	NA	6.25	CH2	G2	-18.7	9.5	3.20
7G-1	NA	6.49	CH2	G2	-16.2	9.9	3.40
12ANW-QUAD-2	NA	6.75	CH2	G2	-19.3	8.3	3.50
11EF-EXT-1	NA	6.76	CH2	G2	-18.6	9.8	3.20
8J-1	NA	7	CH2	G2	-19.0	9.2	3.20
10M-6	NA	7.03	CH2	G2	-18.5	9.9	3.20
10C-2	NA	7.24	CH2	G2	-19.2	9.8	3.50
11M-1	NA	7.75	CH2	G2	-16.5	12.3	3.40
12AE-EXT-3	NA	9	CH2	G3	-19.5	6.8	3.50
9N-EXT-2	NA	9	CH2	G3	-17.5	10.1	3.50
11J-1	NA	9.28	CH2	G3	-18.6	10.4	3.10
12AE-EXT-5	NA	11.3	CH2	G3	-20.3	9.3	3.30
12ASW-QUAD-2	NA	11.3	CH2	G3	-18.3	10.6	3.30
11F-1	NA	11.8	CH2	G3	-19.7	10.0	3.30
10M-8	NA	12	CH2	G3	-18.4	10.3	3.30
11N-1	NA	12	CH2	G3	-19.5	10.3	3.30
5K-1	NA	12.5	CH2	G3	-19.0	10.6	3.30
8F-1	NA	13.8	CH2	G3	-20.2	8.2	3.30
AVERAGE					-18.83	10.36	
SD					.97	1.40	

It is to be expected that large shifts in nitrogen levels and to a lesser extent in carbon values, would be observed when including children from both weaning and post-weaning age groups. It is further expected along the same line of reasoning that there should be noticeable differences between infants and children that are still consuming breast milk and other age cohorts

(adolescents, young adults and adults). As discussed below, large shifts in nitrogen values were observed specifically in relationship to weaning. These, however, were not the only anomalies identified, as there were large swings of both nitrogen and carbon values for individuals of post-weaning age in comparison to within the child cohort individuals and to other non-weaning age groups.

Adolescents

Adolescents represented a small (n=2) sub-sample of those individuals subjected to isotopic analysis (see Table 6.1). All individuals fell between 16 and 17 years of age. One of three (SL267F-3) was identified as showing female morphological characteristics. C13 values had a range of -18.9‰ to -19.3‰ with an average of -19.1‰ and a standard deviation of .28. N15 show levels exhibited a similar small shift with a range of 9.5‰ to 10.2‰ and an average of 9.85‰ and a standard deviation of .49.

Young Adult/Adults

Young adults (18-25 years old) and adults (26-45 years old) were grouped together making up 12.82% (n=5) of the total isotope sample (see Table 6.1). Sex determination was conducted on all five individual resulting in the identification of three males and two females. Carbon values were most enriched at -18.5‰ and showed the greatest depletion for this group at -19.7‰. The average $\delta^{13}C$ was is -19.1‰ with a standard deviation of .58 while the average $\delta^{15}N$ was 10.2 with a standard deviation of .98.

The average $\delta^{13}C$ and $\delta^{15}N$ for males were, -18.7‰ and 9.9‰, respectively. Female adults had an average of -19.7‰ (1‰ more depleted) and 10.65‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively. It should be noted that the enrichment of $\delta^{15}N$ in observed in the female average is, in addition to the small sample, largely a consequence of the $\delta^{15}N$ value for BCL268M-1 (11.6‰). This however, changes when the single female adolescent is added to the adult group. With the additional individual the $\delta^{13}C$ value becomes slightly more enriched by -.27‰ and the $\delta^{15}N$ is reduced by .38‰ to 10.27‰. Similarly, the inclusion of a single male (BCL263G-5) with depleted $\delta^{13}C$ and $\delta^{15}N$ values decreases the $\delta^{15}N$ average from 10.35‰ to 9.9‰ and shifts the $\delta^{13}C$ average from -18.55‰ to -18.7‰.

6.3. Discussion

Clear differences in the carbon and nitrogen isotopic values within the Sirmium sample were identified. These variations were found to relate to differences in age, sex and behavior (diet). No clear relationship could be identified between isotopic values and prevalence of bone and or dental pathology. Furthermore, there was a lack of correlation between the C13 and N15 of specific groups and burial type and or presence of absence of funerary artifacts. In the following section I will discuss the potential diet in relation to the isotopic values for specific age groups in addition to offering explanations for isotopic outliers and differences in diet between males and females

Weaning

The discussion of weaning for the Sirmium sample includes individuals between the ages of 0 and 3 years of age, which incidentally bridges infants and younger children. As a result, there will be some overlap between the weaning discussion and the following section.

Identification for the practice of weaning in archaeological populations comes in the form of direct and indirect evidence. As discussed above, Roman period authors discuss the timing for the introduction of weaning foods in addition to the approximate age for the cessation of breast milk consumption. This type of data, while a primary literary resource, is in fact indirect evidence for the practice of breastfeeding and weaning. Stable isotopes (C13 and N15) comprise the only direct evidence for weaning in archaeological populations.

Evidence for weaning based on carbon and nitrogen isotopes was identified in infants and children between 0 and 3 years of age (see Table 6.4). The majority of individuals under three years of age exhibited clear evidence of elevated $\delta^{15}N$ and $\delta^{13}C$ values as compared to the female average (see Figure 6.4). Average $\delta^{15}N$ for this group (12.01‰) was 1.74‰ more enriched than the female average (10.27‰) while C13 average (-18.74‰) did showed similar enrichment at .83‰. As previously noted, an enrichment of 1‰ for $\delta^{13}C$ and 2-3‰ for $\delta^{15}N$ is expected for individuals that are breast feeding. These parameters were met in most cases or were found to be within acceptable ranges. The individual differences in the carbon and nitrogen values as compared to the female average are depicted in (Table 6.4). Less enriched values for both of these isotopes are expected as weaning foods, of a terrestrial origin, are incorporated into the individual's diet (Fuller et al. 2006).

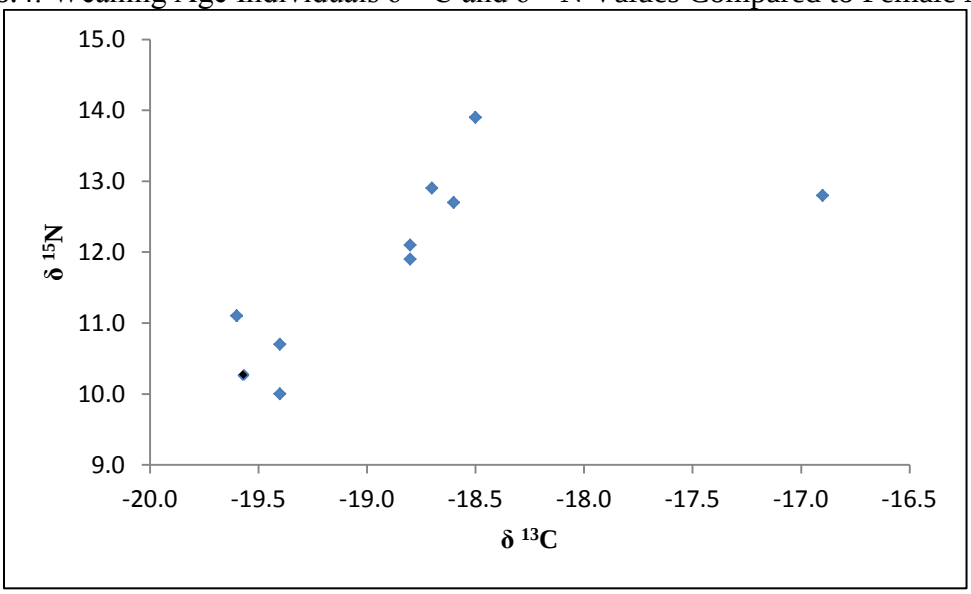
Table 6.4: Weaning Age Individuals

BCINV	AGE	δ ^{13}C	δ ^{15}N	δ ^{13}C-FEM-DIFF[1]	δ ^{15}N-FEM-DIFF[2]
BCL2610M-10	0.083	-19.60	11.10	-0.03	0.83
BCL2612-QUAD 6-1	0.125	-18.70	12.90	0.87	2.63
BCL2610H-2	0.5	-18.60	12.70	0.97	2.43
BCL268N-1	1	-16.90	12.80	2.67	2.53
BCL2612AE-EXT-1	1.19	-18.50	13.90	1.07	3.63
BCL2610M-1	1.5	-19.40	10.70	0.17	0.43
BCL2611J-5	1.75	-18.80	12.10	0.77	1.83
BCL2611N-EXT-1	2.5	-19.40	10.00	0.17	-0.27
BCL2610C-1	2.67	-18.80	11.90	0.77	1.63

[1]Note: δ ^{13}C FEM-DIFF= Difference between infant/child δ ^{13}C and the average Female value (-19.57‰)
[2]Note: δ ^{15}N FEM-DIFF= Difference between infant/child δ ^{15}N and the average Female value (10.27‰)

Interestingly, a two-tailed unpaired t-test focusing comparing N15 values of weaning with that of females returned values that were not quite statistically significant (t=1.9527, p=0.0794). As noted above, the majority of individuals identified as having some incorporation of breast milk in their diet did exhibit N15 values that were more enriched as compared to the female N15 average. The lack of significance between these two groups is likely the result of small sample size of females (n=3). Additionally, one of the female exhibited a comparatively enriched N15 value compared to the remaining 2 females (see Table 6.1). These factors are likely to be at least partially responsible for the lack of statistical significance between the weaning and female groups. Irrespective of the lack of statistical significance the results exhibit that there were differences in diet between females and weaning age individuals. When tested for outlier status (Grubb's Test) the N15 value for SL268M-1 was found to be a significant outlier (z=1.15 p=<.05).

Figure 6.4: Weaning Age Individuals δ ^{13}C and δ ^{15}N Values Compared to Female Average



Key: Black Diamond=Female Average

Evidence for depletion, specifically of C13 values, prior to evidence for less positive N15 values in the same individual, is thought to be associated with the initial incorporation of C13 weaning foods. There is some evidence for more negative C13 values (<1‰ compared to female average) in the majority of individuals (4/7 or 57.14%) that show isotopic evidence for weaning. No clear pattern could be identified, however, which would clearly indicate that this sample showed an age related distinction for the incorporation of weaning foods.

There is some evidence of a decline in N15 enrichment beginning around 6 months old. This, however, is difficult to fully discern and there is a certain amount of uncertainty of the pattern as the overall sample size for this cohort is relatively small. Furthermore, the peak enrichment was observed in an individual (BCL2612AE-EXT-1) aged to be a little more than one years old. This being said, the cessation of breast milk for the Sirmium sample seems to have abruptly (see Figure 6.5) occurred between 2.5 and 3 years of age. Children aged 3 years old and above, do not

exhibit carbon and nitrogen enrichment that would be associated with consumption of breast milk. Those individuals (post-3 years old), that did show elevated C13 and N15 values, due to advanced age, were likely to have been caused by variables other than consumption of breast milk.

Weaning Outliers

While the majority of specimens within this group recorded elevated N15 and C13 values indicating evidence for consumption of some breast-milk, there was some variation in the isotopic values outside what would be expected. Four individuals deserved further discussion.

Of interest are the C13 and N15 values from the 3 week old (SL2610M-10). This infant exhibited elevated nitrogen values (11.1‰) and depleted C13 (-19.6‰). While the delta N15 value is between 1.13‰ and 1.28‰ below that of the other infants (individuals) within this group it is, in most cases more enriched than post-weaning children by an average of 1.34‰ and approximately 1‰ above that of all adolescent and adults combined. The elevated N15 suggests that there is some evidence of incorporation of breast milk in the diet of individual from a very early age, a pattern observed in other Roman Age archaeological samples. More difficult to explain is the depleted C13 for this infant. Fuller et al (2006) encountered similar combined isotopic values for a young individual (C13=-19.4; N15=11.2) but did not offer a clear explanation. Elevated nitrogen values with comparably lighter than expected C13 values, similar to those observed in, SL2610M-10, have also been identified in an early Roman Christian sample from Rome (Rugters et al 2009). Here the authors suggest that these values are related to consumption of fresh water fish. Based on the age of the individual in question from the Sirmium

collection, it is highly unlikely that direct consumption of Sava fish or other fresh water fish was the variable leading to the isotopic values observed (unless females were consuming fresh water fish). Other individuals from the weaning cohort do exhibit depleted C13 values but do so with comparable depleted nitrogen values. This being said, infants tested by Fuller et al (2006) show overall lighter C13 values with enriched N15 values. Evidence such as this, leads to the possible conclusion that the isotopic values of SL2610M-10 is likely related to values of the mother and that while the infant does exhibit some evidence for breast feeding the mother is likely to have consumed a diet that relied heavily on terrestrial C3 plants.

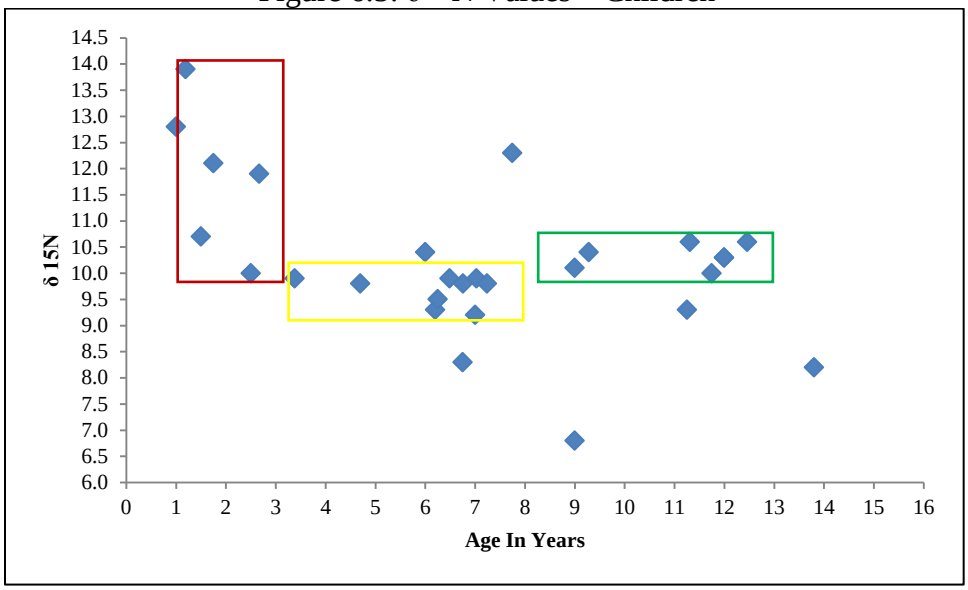
Two children (BCL2611N-EXT-1 and BCL2610M-1), aged between 1.5 and 2.5 years old, exhibited C13 and N15 that were depleted below that what is expected for children that are in the process of weaning. C13 values are only slightly enriched as compared to the female average (see Table 6.5). When the N15 values where compared to the female average for this isotope it was found that one of the individuals exhibited slight enrichment (.43‰) while the other child was depleted by .27‰ as compared to females. To further validate the observed differences in N15 and C13 levels for these two children of weaning age, their isotopic values were compared to the average C13 and N15 for the remaining individuals showing evidence of breast milk incorporation. The difference here (see Table 6.5) showed that BCL2611N-EXT-1 was depleted by .84‰ and 1.79‰ for C13 and N15, respectively as compare to the averages for this group. BCL2610M-1 followed a similar pattern for C13 was but depleted by more than 2.5 times the standard deviation (.89‰) of this group and depleted by slightly less than 1.5 times N15 value for BCL2611N-EXT-1. Based on these findings, it is likely that these two children did not consume breast milk or that they were weaned at much earlier.

The last individual that exhibited values outside the expected range for breasting feeding/weaning was a child aged to 1 years old. The N15 value (12.8) was found to fall within the accepted trophic range for breastfeeding individuals. The C13 level (-16.9‰) was, however, 2.67‰ more enriched than the female average. A trophic level effect of ~1‰ is expected for breastfeeding individuals. Elevated C13 values, with corresponding enriched N15, for weaning aged children, similar to those identified for BCL268N-1, were recorded by Keenleyside et al (2009). Here, the diet was based on terrestrial fauna with a considerable addition of marine resources (fish). The enrichment of C13 and N15 for breastfed aged children found in the Keenleyside (2009) study is likely related to an increased consumption of fish (marine). The single child from Sirmium exhibiting this pattern unfortunately does not have correlated females with related C13 and N15 values. As such a link between the enriched C13 values and female consumption of marine resources cannot be made.

Post-Weaning Age Children

As noted in the previously, the child cohort was shown to have 3 distinct age related clusters defined by shifts in N15 values (see Figure 6.5).

Figure 6.5: $\delta^{15}N$ Values – Children



G1 Children: Red Box; G2 Children: Yellow Box; G3 Children Green Box

The youngest child sub-group (G1), consisting of children between 1 and 2.67 years old, had the most elevated levels for N15, of which the majority of individuals had similarly enriched values as those from the infant group. There was no significant difference in the N15 values between infants and members from child G1 (unpaired t-test: t=.5658; p=.5892). The older two child sub-groups (G2 and G3) both exhibited N15 values that were more depleted than those of child sub-group G1. A two-tailed unpaired t-test confirmed that the difference between G1 and older child sub-groups (G2 and G3) was statistically significant (t=3.7319 p=.0018; t=3.26 p=.005, respectively). As discussed above, elevated N15 values were found in infant and children between 1 and 3 years of age and are likely related to the trophic effect and more specifically regarding this group of children, the trophic level effect related to the consumption of breast-milk. Therefore, the difference between N15 values for G1 children and the significantly more

depleted N15 values recorded for G2 and 3 children is attributed to the cessation of breast-milk in the diet of G2 and G3 members. While it is clear that based on individual comparisons to the average female N15 G1 children show evidence for diets that include breast milk (see Table 6.5 shows individual differences between N15 of G1 children and Female average), a two tailed unpaired t-test found that there was no significant difference between G1 and females regarding N15 values (t=1.7226 p=.1286). This finding is similar to that when the weaning age group (infants and G1 combined) was compared to females (see above).

Table 6.5: Children (G1) Weaning Age Individuals

BCINV	AGE	δ ^{13}C	δ ^{15}N	δ ^{13}C-FEM-DIFF[1]	δ ^{15}N-FEM-DIFF[2]
BCL268N-1	1	-16.90	12.80	2.67	2.53
BCL2612AE-EXT-1	1.19	-18.50	13.90	1.07	3.63
BCL2610M-1	1.5	-19.40	10.70	0.17	0.43
BCL2611J-5	1.75	-18.80	12.10	0.77	1.83
BCL2611N-EXT-1	2.5	-19.40	10.00	0.17	-0.27
BCL2610C-1	2.67	-18.80	11.90	0.77	1.63

[1]Note: δ ^{13}C FEM-DIFF= Difference between individual children (G1) δ ^{13}C and the average Female value (-19.57‰)

[2]Note: δ ^{15}N FEM-DIFF= Difference between individual children (G1) δ ^{15}N and the average Female value (10.27‰)

The lack of significant difference is likely the result of a few factors including, small sample size and specific individuals both from the female cohort and G1 sub-group that have N15 values that are outside with the expected values for these groups. As discussed above the two children from G1 that were likely not breast fed or had ceased breast feeding prior to death had N15 values of 10.0‰ and 10.7‰ (see above for detailed discussion). Similarly, both of these children also exhibited depleted C13 values, furthering strengthening the idea that they were not breast fed or had ceased consumption of breast milk prior to death. Removal of both of these children from statistical analysis would effectively lead to a shift in the outcome when testing for significant difference between females and G1. It was, however, decided that the presence of variation observed with these individuals is important for understanding differences in dietary behavior

and therefore the children with evidence for depleted N15 values remained as part of all statistical tests. The presence of individuals with no or little evidence for breast feeding supports the idea that while there was similarity in the timing for cessation of weaning in varied regions of the Roman Empire, there is evidence to support that all cultural practices such as this varied regionally but also locally, or within a specific population.

Post weaning children formed two clusters (G2 and G3) related to of N15 values and age. The average N15 (9.84‰) for Group 2 children (3.38-7.75 years old) showed a depletion of this isotope below that of average female $\delta\ ^{15}N$ (10.27‰) with the majority of G2 members with values between 9.2‰ and 9.9‰ (see Table 6.6). This N15 decrease is followed by child sub-group G3 (9-13.8 years old) showing the majority of individuals with N15 values slightly more enriched than G2 and largely falling between 10.0‰ and 10.6‰ and within the average for females (see Table 6.6).

Table 6.6: Children G2 and G3 $\delta^{15}N$ Values Compared to Female/Male $\delta^{15}N$ Average

BCINV	AGE	$\delta^{15}N$	[1]FEM DIFF $\delta^{15}N$	[2]MALE DIFF $\delta^{15}N$	[3]M/F DIFF $\delta^{15}N$
12A-1	3.38	9.90	-0.37	0.00	-0.18
12ASW-QUAD-1	4.7	9.80	-0.47	-0.10	-0.28
12ANW-QUAD-1	6	10.40	0.13	0.50	0.32
7F-1	6.2	9.30	-0.97	-0.60	-0.78
10M-5	6.25	9.50	-0.77	-0.40	-0.58
7G-1	6.49	9.90	-0.37	0.00	-0.18
12ANW-QUAD-2	6.75	8.30	-1.97	-1.60	-1.78
11EF-EXT-1	6.76	9.80	-0.47	-0.10	-0.28
8J-1	7	9.20	-1.07	-0.70	-0.88
10M-6	7.03	9.90	-0.37	0.00	-0.18
10C-2	7.24	9.80	-0.47	-0.10	-0.28
11M-1	7.75	12.30	2.03	2.40	2.22
12AE-EXT-3	9	6.80	-3.47	-3.10	-3.28
9N-EXT-2	9	10.10	-0.17	0.20	0.02
11J-1	9.28	10.40	0.13	0.50	0.32
12AE-EXT-5	11.25	9.30	-0.97	-0.60	-0.78
12ASW-QUAD-2	11.31	10.60	0.33	0.70	0.52
11F-1	11.75	10.00	-0.27	0.10	-0.08
10M-8	12	10.30	0.03	0.40	0.22
11N-1	12	10.30	0.03	0.40	0.22
5K-1	12.46	10.60	0.33	0.70	0.52
8F-1	13.8	8.20	-2.07	-1.70	-1.88
Average		9.76	-0.51	-0.14	-0.32

[1]Note: $\delta^{15}N$ FEM-DIFF= Difference between individual children (G2 and G3) $\delta^{15}N$ and the average Female value (10.27‰)
[2]Note: $\delta^{13}C$ MALE-DIFF= Difference between individual children (G2 and G3) $\delta^{13}C$ and the average Male value (9.90‰)
[3]Note: $\delta^{13}C$ M/F-DIFF= Difference between individual children (G2 and G3) $\delta^{13}C$ and the combined average Male and Female value (10.08‰)

When an unpaired two tailed t-test was utilized comparing G2 and G2 N15, however, it was found that there was no significant difference between G2 and G3 (t=.3918 p=.6993) regardless of the observed clustering for both groups. In fact G2, of which the majority of members had more depleted N15 values as compared to G3, had an average which suggested that the group had more enrichment of N15 as compared to G3 (G2 AVG=9.842; G3 AVG=9.660). The difference in averages and the lack of significance was found to be the result of the presence of a number of individuals in both groups that effectively altered the expected averages as a result of abnormally enriched or depleted N15 values found in both groups. SL2611M-1 aged 7.75 had a N15 value of 12.3‰ which is enriched within the range for individuals of breast feeding age and slightly more than 2.5 standard deviations above the mean for this group. Removal of the child from G2 effectively drops the average for G2 to 9.62‰ slightly below that of G3.

Similar to G2, G3 also incorporates individuals that fall outside pattern of for this particular group. SL2612AE-EXT-3 and SL268F-1 returned a N15 value of 6.8‰ (~2.3 SDs below the average for G3) and 8.2‰, respectively. Removal of both values increased the average of G3 to 10.2‰ which is close to the N15 average for females (10.27‰). Statistical analysis does show evidence for significant difference with the removal of these three individuals but again, in the same reasoning as discussed above for G1, it was decided that the presence was not an indication of measurement error but instead evidence of variation of individual diet and therefore should not be removed.

Both G2 and G3 individuals were compared to the female and male N15 averages in order to identify possible differences in diet across age and sex groups. G2 individuals were found to be largely, with regards to nitrogen, lighter compared to both adult males and adolescent and adult females. More specifically, of the 12 children comprising G2, 11 were found to have lighter N15 values (see Table 6.6-column 4) compared females with an average difference of .43‰ while the difference between G2 and adult males (see Table 6.6-column 5) was significantly smaller (.06‰). N15 values for G3 children were overall more depleted with 6 of 10 individual having lighter isotopic values as compared to the female average (see Table 6.6-column 4) and average difference of .61‰. When compared to male N15 average, only 3 of 10 children were found to have more depleted N15 scores with 2 of the 3 children having N15 values significantly more depleted values.

The overall pattern for children (1-13.8 years old) is one of enrichment, depletion and slight enrichment of N15 values. The initial enrichment observed in G1, as noted above, is related to

breastfeeding. The difference between child G1 and child G2 as discussed above is related to the cessation of breast milk and the shift to a reliance on a diet most likely consisting mainly of a terrestrial diet of C_3 origin. It is expected that after the completion of weaning and the consumption of a diet similar to that of adults, N15 values of children should approach the average of adult females. The decrease of nitrogen values for individuals between 3 and 8 years old (G2) however, fell below the average N15 value of females of 10.27‰. In fact the majority of children within this group, as noted above, had nitrogen values between 9.20‰ and 9.90‰. The decrease below that of the female average is thought to be related to a diet that is more protein deficient or to the related the physiological needs of the body during periods of intense growth (Prowse et al 2008).

The corresponding C13 values for children did not show similar patterns of clustering related to shift in age. Evidence for enrichment and depletion were found in all sub-groups for children. In fact when the same sub-groups of children used for comparing N15 values were used for C13 comparison, including comparison between weaning age and post weaning age children, no significant difference was observed between groups. It was found, however, that the majority of post-weaning children had C13 values between -19.5‰ and -18.5‰ which falls below the average for females. While individual sub-group patterns were not identified, it was observed that of the 22 children forming G2 and G3, 18 individuals had C13 values that were more enriched when compared to the female C13 average (see Tables 6.7). Additionally, when males were added to the female cohort the total children with C13 enrichment above adults (male and female) dropped to 13. Interestingly, however, the average C13 for the combined G2 and G3

children was only .05‰ more depleted when matched with the male C13 average (-18.7) as compared to the a difference of .82‰ more enriched over females.

Table 6.7: Children G2 and G3 **δ ^{13}C** Values Compared to Female/ Male **δ ^{13}C** Average

BCINV	AGE	δ ^{13}C	[1]FEM DIFF δ ^{13}C	[2]MALE DIFF δ ^{13}C	[3]M/F DIFF δ ^{13}C
12A-1	3.38	-20.20	-0.63	-1.50	-1.07
12ASW-QUAD-1	4.7	-19.90	-0.33	-1.20	-0.77
12ANW-QUAD-1	6	-19.10	0.47	-0.40	0.03
7F-1	6.2	-16.90	2.67	1.80	2.23
10M-5	6.25	-18.70	0.87	0.00	0.43
7G-1	6.49	-16.20	3.37	2.50	2.93
12ANW-QUAD-2	6.75	-19.30	0.27	-0.60	-0.17
11EF-EXT-1	6.76	-18.60	0.97	0.10	0.53
8J-1	7	-19.00	0.57	-0.30	0.13
10M-6	7.03	-18.50	1.07	0.20	0.63
10C-2	7.24	-19.20	0.37	-0.50	-0.07
11M-1	7.75	-16.50	3.07	2.20	2.63
12AE-EXT-3	9	-19.50	0.07	-0.80	-0.37
9N-EXT-2	9	-17.50	2.07	1.20	1.63
11J-1	9.28	-18.60	0.97	0.10	0.53
12AE-EXT-5	11.25	-20.30	-0.73	-1.60	-1.17
12ASW-QUAD-2	11.31	-18.30	1.27	0.40	0.83
11F-1	11.75	-19.70	-0.13	-1.00	-0.57
10M-8	12	-18.40	1.17	0.30	0.73
11N-1	12	-19.50	0.07	-0.80	-0.37
5K-1	12.46	-19.00	0.57	-0.30	0.13
8F-1	13.8	-20.20	-0.63	-1.50	-1.07
Average		-18.78	0.79	-0.08	0.36

[1]Note: δ ^{13}C FEM-DIFF= Difference between individual children (G2 and G3) δ ^{13}C and the average Female value (-19.57‰)
[2]Note: δ ^{13}C FEM-DIFF= Difference between individual children (G2 and G3) δ ^{13}C and the average Male value (-18.70‰)
[3]Note: δ ^{13}C M/F-DIFF= Difference between individual children (G2 and G3) δ ^{13}C and the combined average Male and Female value (-19.133‰)

A comparable pattern and relationship was found between the combined G2 and G3 average for N15 as compared to male and female N15 averages (see Table 6.7-column 4-5). The similarity between children and males with regards carbon and nitrogen values might suggest that both of these groups were consuming similar type foods as compared to females, which would point to differential dietary that cross both age and sex boundaries. Evidence for differential diets based on isotopic analyses has been identified in Roman period populations (Prowse et al. 2004).

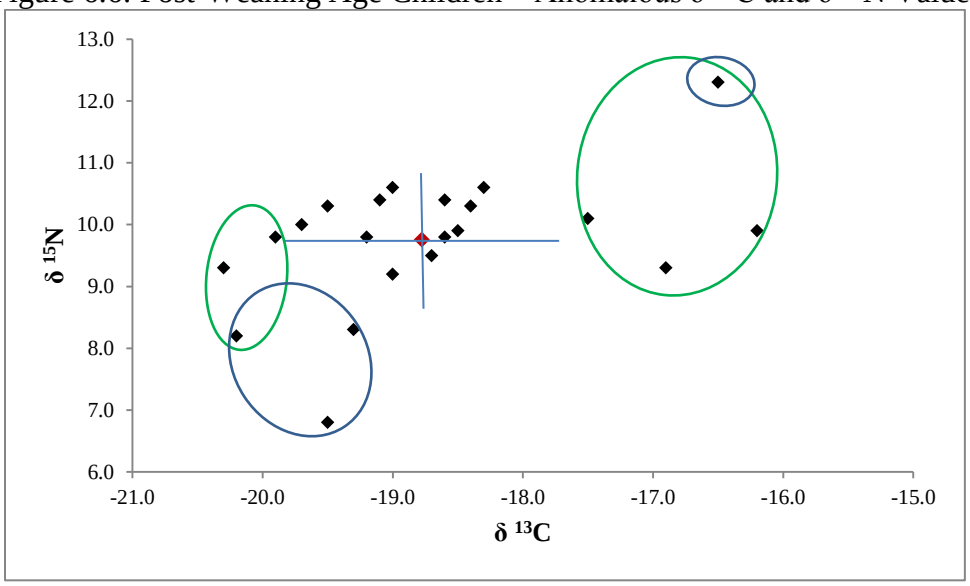
The relatedness between the C13 and N15 values for post-weaning children and those of adult males should be viewed with caution as the sample size for males, females and children are small. In addition to sample size, there are a number of individuals that exhibit elevated carbon and nitrogen values that fall significantly outside the mean. These children effectively shift the average C13 and N15 values and in doing so, could suggest a diet that would be an incorrect representation of the diet of post-weaning child sample as a whole.

Post-Weaning Age Children Outliers

There were a number of individual from this study that revealed individual C13 and N15 values or combined values that were found to be outside the normal distribution for both or combined values. This section will discuss these individuals in more detail offering some explanation.

Of the 22 individuals comprising post-weaning children, four individuals exhibited enriched C13 values above the expected values for a C3 terrestrial based diet (see Table 6.7 and Figure 6.6). In addition, with a range of -16.2‰ to -17.5‰, they were also significantly more enriched compared to all individuals by as much as 4.1‰. Abnormally light N15 values were observed in three children (6.8‰ – 8.3‰) while one child also was found to have enriched N15 values in the range of breastfeeding/weaning age individuals (see Table 6.6 and Figure 6.6).

Figure 6.6: Post-Weaning Age Children – Anomalous δ ^{13}C and δ ^{15}N Values



Key: Green Oval= δ ^{13}C Values > 1 SD; Blue Ovals= δ ^{15}N Values >1 SD; Red Diamond=Children (post-weaning) Average; Blue Lines= 1 SD

Anomalous C13 Values

Significantly elevated carbon (enriched) can be a symptom of diet that incorporated a large percentage of protein from marine or freshwater resources, specifically that of fish. The lack of corresponding enriched nitrogen levels for at least two of the four children (BCINV7G-1 and BCINV7F-1) would suggest that the enrichment of carbon was not related to consumption of freshwater or marine resources. According to, (Katzenberg 1999), however, depleted nitrogen with enriched C13 could still be the result of marine resource intake if it was minimal and or if the aquatic animal (fish) was lower on the food chain (more depleted N15 value). It is more likely, however, that in relation to these two individuals, there was significant consumption of C4 plants. Probably in the form of consumption of animals that fed on a diet of C4 flora. Slightly less enriched that than the two children previously mentioned, BCINV9N-EXT-2 exhibited elevated C13 (-17.5‰) that was 1.04‰ more enriched than the average for post-weaning age children. N15 for this child was slightly elevated at 10.1‰ as compared to all non-weaning age children. As with the two previous children the enriched carbon with relatively light nitrogen

could be the result of consumption of C4 plants. Alternatively, again some incorporation of marine/riverine food (if a lower trophic level) could have played a role the isotope values for this child. The last child with enriched C13 incidentally had corresponding enrichment of their N15. BCINV11M-1 aged to be 7.75 years old displayed a C13 value of -16.5‰ and a nitrogen score of 12.3‰. This is the only individual of the entire sample with the exception of a weaning age individual, in which both isotopes were enriched to this level. Similar isotope values were found in both younger and older individuals from Roman Period (2^{nd}-3^{rd} CE) in Tunisia (see Keenleyside et al. 2009) where a significant portion of the diet consisted of marine resources (fish). Sirmium, however, is not located in close proximity to the sea and there are no other individuals share similar isotope values.

Anomalous N15 Values

With the exception of the child mentioned above with enriched N15, three children were found to have N15 that deviated significantly (more depleted), by as much as 2.96‰, from the post-weaning age child average (9.76‰). These children, in addition to the depleted N15, also have light C13, in the range of -19.3‰ to -20.2‰. The depleted N15 and corresponding C13 values suggest that the protein portion of their diet was almost exclusively of a terrestrial plant origin. Isotopic studies conducted by Richards et al (1998) and Prowse et al (2004) both identified individuals with similar depleted N15 values in a Roman Age populations and equated the values to diets likely to have been exclusively or largely depended on terrestrial C3 plant based diet. Other children exhibited C13 as depleted as these three children (see Table 6.3) but they did not, however, have N15 values as depleted strengthening the idea that within the child cohort there was differences in post-weaning age diets.

Post-Weaning Age Children (All) Diet

Overall diet based on average C13 (-18.78‰) for post-weaning age children shows enrichment over female mean C13 by approximately .8‰ which would indecently fit a terrestrial C3 based diet with some inclusion of marine resources. According to Krueger and Sullivan (1984) a mixed diet consisting of marine and C3 resources should lead to C13 values somewhere between -16.0‰ and -19.0‰. The Sirmium child G1 and G2 fit this pattern for C13. The corresponding N15 average for these post-weaning children do not, however, show enrichment of this isotope in line with a mixed marine diet. Consumption of food with a C4 origin could lead to the enrichment of C13 without elevated N15 as was the pattern observed at the multi-period site of Lepenski Vir (see Bonsall et al. 2004).

The relatively large range in post-weaning age carbon (Diff=4.1‰) and nitrogen (Diff=5.5‰) values in addition to a large respective SD is suggestive of greater individual variation in diet. This can be compared to a smaller range of values at St Callixtus in Rome (Rutgers et al. 2009) where the difference in C13 and N15 was 1.9‰ and 2.2‰, respectively, in which access to food in addition and consumption was similar for individuals buried in this particular cemetery.

Adolescents and Adults Diet

Adolescents comprise the smallest sub-group of the isotopic sample (n=2). The carbon and nitrogen values for these two individuals (see Table 6.1) differ slightly with regards to both isotopes and may suggest that there was some difference in diet including possible non-terrestrial food consumption for one of the two individuals (BCINV10H-1). This, however, should be viewed with caution due to the small sample size. The individual that retained the more depleted

C13 and N15 values was identified morphologically as a female and most likely consumed a diet that consisted largely of a terrestrial based C3 diet. The lack of the necessary elements did not allow for sex identification of the second adolescent individual.

A total of five individuals were identified as adults of which two were females and three were males. Males ranged in age between 37 and 44 years of age while adult female were found to be young ranging in age between 22 and 24 years of age. The addition of the adolescent female effectively changes the age range to 16-24 years old.

Male/Female Diet

Differences in diet related to sex have been identified by researchers using stable isotopic analysis on Roman Age populations (Prowse et al. 2005). The sample of individuals that could be identified as male/ female is small and cannot truly represent the overall dietary trends for adult male and females. It can however, offer a starting point to which future work can be added. Historical writings complied during the early Empire suggest that there were restrictions, specifically in relation to females, with regards to and the access and or quantity of different types of food and sex (see Garnsey 1999). Females, regardless of the physiological needs (specifically in relation to pregnancy) were thought to require diets that were sub-par with regards to protein. The extent to which these parameters were followed seems to vary considerably throughout the Empire and likely is the result of the overall availability of resources and local cultural practices.

The Sirmium sample while small does indicate that there was some evidence for a difference the diet of males and females. Adult males were found to be on average 1‰ more enriched compared to adult females. The difference was found to be statistically significant (p=.0178 t=4.7434). This changed, however, when the adolescent female was added. A paired t-test suggested that the difference between male and female C13 was not quite statistically significant (p=.0931 t=3.0431). No significant difference was found between males and females (with and without the adolescent female) for nitrogen. While the male N15 average was lighter compared to females (9.9‰ vs. 10.27‰), two of the three males exhibited heavier N15 compared to 2 of the females (see Table 6.1). Two of the males with enriched C13 and N15 show potential for differential diet that may have included marine fish or higher tropic level riverine fish. The single male with the most depleted C13 and N15 values related more to a diet largely based on terrestrial based food resources.

Based on the combined isotopic values for females it is likely that they were consuming a diet mainly comprised of food of a C3 terrestrial origin. The relative light N15 values also point to a low also point to terrestrial based protein with the exception of BCINV8M-1 which exhibited an enriched N15 (11.6‰) and a depleted C13 (-19.6‰). The enrichment of the female N15 is 1.7‰ above the average N15 for all post-weaning age individuals and 1.4‰ above the N15 for other adults (not including the adolescent female). The isotopic values for this individual shows some similarities to Mesolithic and Early Neolithic period skeletons from the Iron Gates region (Bonsall et al. 2004), in which consumption of high trophic Danuban fish were noted as reason for the elevated N15 values. The lack of zooarcaheological material makes connections to a diet of riverine fish difficult.

6.5 Inter-Site Comparisons

Paleodiet research using stable carbon and nitrogen isotopes are becoming more common. Dietary isotopic research focused on Roman Imperial world is largely clustered in a few provinces of the vast geographic region ruled over during the period of the Roman Empire leading to an uneven proportion of studies representing those specific regions. Within the last 10-15 years many of the skeletal samples utilizing stable carbon and nitrogen isotopes for paleodiet analysis originate from Roman Britain (Richard and Hedges 1998; Fuller et al. 2006; Chenery et al. 2010; Redfern et al. 2010; Muldner et al. 2011), Roman Italy (Prowse et al. 2004; Prowse et al. 2005; Prowse et al 2008; Craig et al. 2009; Rutgers et al. 2009) and Roman North Africa (Keenleyside et al 2009). These samples are representative of three Roman Provinces with many of the articles utilizing the same archaeological sample. The work conducted by these authors have begun to set the isotopic framework for these geographic regions in addition to answering questions specifically related to the dietary behavior of Imperial Roman populations.

At the time of writing this dissertation, no skeletal material from Pannonia dated to the Late Roman Empire had been subjected to paleodietary research using stable carbon and nitrogen isotopes with the exception study conducted by Bonsall et al. (2004) on multi-period occupation Lepenski Vir of the Iron Gates Region. In this regards the Sirmium sample represents the only material from Late Roman Lower Pannonia to be subjected to dietary isotopic analysis. This factor also plays a role in limitations for inter-site comparison.

In addition to differences in cultural practices that govern diet and rules regarding access to food, local environment can also lead to different availability of food resources. Furthermore, as noted

previously, climate (temperature) can affect the C13 values. These factors make cross site and inter-regional comparison difficult. Comparisons made between the isotopic results from Sirmium that those from other regions of the Roman world must be viewed with caution.

Infant and weaning age children followed similar patterns with regards to enrichment of both N15 and C13 values in comparison to other Roman Period sites. Fuller et al. (2006) indicated that children from a Roman British site of Queensford exhibited evidence for incorporation of non-breast milk sometime around 6 months with complete cessation by 3 years of age. Similar patterns were found at Isola Sacra (Prowse et al. 2008) in Roman Egypt (Dupras et al. 2001) and in Roman North Africa at Tunisia (Keenleyside et al 2009). At Sirmium, while the overall weaning age sample was small, no children older than 3 were exhibited any evidence of elevated N15 or C13 that could be related to consumption of breast milk. The similarities observed between these sites, which show considerable geographic variation, point to a common cultural practice that crossed spatial and cultural boundaries. Furthermore, the isotopic evidence from Sirmium and other Imperial Roman Age sites are in line with the historical medical authors of the time period.

Based on the post-weaning age isotopic values it is likely that there was some variation in individual diet at Sirmium. The average post-weaning C13 and N15 did exhibit some similarities to other Roman Age samples but also display clear discrepancies (see Table 6.8).

Table 6.8: Comparisons to Other Roman Age Isotopic Samples

SITE	C13	C13 SD	N15	N15 SD	REGION	DIET
SIRMIUM	-18.86	1.03	9.84	1.01	SERBIA	
ISOLA[1]	-18.8	0.3	10.8	1.2	MID-ITALY	MIXED C3 AND MARINE
TUNISIA[2]	-17.7	0.6	13.4	1.8	NORTH AFRICA	SIGNIFICANT MARINE
VELIA G1[3]	-19.5	0.2	8.2	0.7	SOUTH COASTAL ITALY	PROTIEN HERBIVORS
VELIA G2[3]	-19.3	0.3	11.2	1.3	SOUTH COASTAL ITALY	PROTIEN HERBIVORS MARINE FISH
ST CALLIXTUS[4]	-19.8	0.4	10.6	0.8	ROME	MIXED C3 WITH H2O FISH

[1]Prowse et al 2008; [2]Keenleyside et al 2009; [3]Craig et al 2009; [4]Rutgers et al 2009

Sirmium shows some evidence of similar C13 values with Isola Sacra but largely stands out from other Roman Age sites listed above with regards to C13. N15 is depleted in comparison to other Roman sites, with the exception of Velia G2. The combined enriched C13 and depleted N15 isotopes is not observed in any of the other sites and therefore might be suggestive of different diets being consumed by the individual at these sites. All four sites listed above represent diets that in part consisted of some marine or fresh water protein except of Velia G2, which was largely based on food with a terrestrial C3 origin. It is likely that as a whole, post-weaning individuals consumed a diet that consisted of C3 terrestrial foods with some C4 originated food and possible some riverine fish.

6.6 Conclusion

The C13 and N15 isotopic values for individuals from Sirmium exhibited a large range thereby pointing to a population that in part consumed somewhat different diets. Differential access to food based on social status, age and biological sex are potential factors that might have led to disparity found between isotopic values of individuals from Sirmium. This being said the overall dietary trend is likely to have been one of mixed diet C3 terrestrial (meat and grains) origin with some evidence for consumption of C4 terrestrial based food. The pattern observed for the Sirmium sample largely follows that of the 'Typical Roman Diet' which according to Garnsey (1999) consisted of cereals, olives and wines and some addition of meat. As would be expected, deviations from the trend were observed.

Baring the weaning age individuals, the greatest variation in isotopic values (for both C13 and N15) were observed in the post-weaning age children. Furthermore, within this cohort, the only clear evidence pointing to consumption of foods with a C4 origin was identified with any certainty. It is known from historical records that millet, a C4 plant, was cultivated in Pannonia during the Roman period. While it was believed to be a sub-standard grain, to be used during famine, as animal feed or by the poor, as compared to wheat, the frequency of use might have been increased in regions where it was more accessible as was the case in Pannonia.

Post-weaning age children also included individual comprising the most deplete C13 and N15 values as compared to all other groups. Here, the diets of these children were likely to consist largely of C3 origin with at least two children consuming a diet that was largely plant based with little evidence of animal based products. The discrepancies both within the post-weaning age cohort and compared to adolescents and adults is suggestive of both differences in diet but it also potentially points to a distribution of a poorer diet for children. Alternatively, the lack of animal protein in the diets of these children might also be representative of evidence for differences in socio-economic classes.

Some individuals, representing all age groups, exhibited isotopic values that might indicate diets that included some marine or fresh water fish. While this must be viewed with caution as the zooarchaeological and historical evidence for diet at Sirmium is lacking, it is nonetheless important to consider given the geographic proximity of Sirmium to the Sava River.

The role of fresh water fish in Roman Period not clear cut. Fresh water fish was not considered to be a high status food and furthermore as compared to its marine counterpart it was valued at between ½ and 1/3 of the price. On the bank of the Sava, access to an abundant and relatively cheap source of protein would seem to lead to a larger inclusion of this resource into the diet of individuals from Sirmium than what is observed based on the isotopes from this sample. While the evidence for consumption of fresh water fish during the Roman Empire is minimal, there is some evidence that would suggest that for some populations this resource played a large role in their diet (see Rutgers et al., 2009). Unfortunately, due to the lack of Sava River fish samples a relationship between the isotopic values of the human bone samples and a diet that include fish from the Sava could not be confidently made.

The evidence for weaning was represented in infants and children between 0 and 3 years of age. This pattern was similar to other isotopic studies on Roman weaning practices. Furthermore, the basic timing for the cessation of breast milk (~3 years of age) followed the suggestions of medical writers of the time pointing to a cultural practice that crossed geographic and cultural boundaries.

The Sirmium isotopic work currently represents the only paleodiet research for this Roman Period site and therefore, has begun to set the foundation for understanding Roman diet in Imperial Sirmium. It is also recognized that the isotopic work is based on a small sample and may not completely represent the full dietary patterns at Sirmium. As such, more work is needed from an isotopic view point but also from zooarchaeologucal and historical avenues.

Chapter 7

Discussion

7.1 Introduction

It is important to remember that disease irrespective of the type does not happen in a vacuum. Biological, cultural and environmental variables should be taken into consideration when attempting to interpret the lesions identified on skeletal and dental material. As discussed in previous chapters nutrition, exposure to pathogens, access to preventative and post-preventive health care, and economics, all play a role in exposure, contraction and the progression to a state of disease impairment. In addition, the complexity of understanding the relationship between diseases, as they are often found in the same person can help to understand the morbidity and mortality of individuals and specifically in the case of this dissertation, non-adults.

Evidence for physiological stress manifested as abnormal bone and dental morphology affected individuals from all age categories from the Sirmium sample, with the exception of individuals from the fetal and neonatal cohorts. The prevalence for bone pathology peaked around 70% with dental pathology showing a higher prevalence, in the range of 86% affected, with 73.77% of individuals exhibiting both bone and dental pathology. Overall, children aged between 6 and 14 showed the highest prevalence for each type of pathological condition (bone and dental) that was evaluated for this thesis with the exception of hypoplasia where the difference between CH2 and CH1 was significant (see CHP 5). The differences between CH2 and other age cohorts for pathology, was however, found in all cases not to be statistically significant.

7.2 Bone Disease

7.2.1 Cribra Orbitalia and Porotic Hyperostosis

Cribra orbitalia (CO) and Porotic Hyperostosis (PH) are both common findings in archaeological skeletal material. As discussed previously (see chapter 4) both of these morphological features are likely the result of physiological stress suffered during early growth and development, as active lesions are not found in older individuals. The juveniles from Sirmium, Locality 26 cemetery had an overall frequency of slightly less than 60.5% of showing macroscopic characteristics associated with CO and PH, with the majority of affected individuals being members of the CH2 (6-14) age cohort. As noted in chapter 5, the differences between all age groups were found not to be significant. The relatively high frequency of CO at Sirmium is similar to the prevalence recorded by others for Roman period material (Slaus 2008; Wheeler 2010; Facchini et al. 2004; Liebe-Harkort 2010).

The high prevalence of CO/PH affecting the juvenile segment of this population may indicate a deficiency in dietary intake of specific food sources containing nutrients such as iron and or vitamin B12 as these morphological features have often been linked to iron deficiency and megaloblastic anemia (see Stuart-Macadam 1987; Walker et al 2009). As discussed in Chapter 4, access to foods (i.e. red meat) containing adequate quantities of these two nutrients may have been under cultural control thereby reducing or eliminating food resources to specific groups based on occupation, status, sex and age. Differential diets specifically in relationship to non-adults may have played a role in the prevalence CO/PH in this sample. Carbon and nitrogen isotopes, discussed in Chapter 6, may shed some light on potential dietary deficiency in those with CO, specifically in the older child cohort. Post weaning children displayed an overall

depleted ^{15}N level compared to the females (see CHP 6). The lower nitrogen may indicate a diet that contained a lower level of protein which may include a diet that was deficient in iron and vitamin B12 source foods, which would lend support for a dietary origin for CO and PH. Chapter 4 and 6 discuss in more detail the potential for differential access to food specifically related to children and other non-adults. Difference in diet was known to have been a part of Roman life between adults and children but there is also some evidence for inequality of diet between male and female children (see Garnsey 1999), with males being favored over females. It is clear from the isotopic analysis that children differed in their carbon and nitrogen values (see Chapter 6), and therefore diet, but further explanation related to the sex of the individuals cannot be hypothesized due the inaccuracy of sex identification of children.

In addition to the lack of access to food sources, consumption of specific types of food may inhibit the absorption of iron playing a role in the high instance of CO/PH. Millet, a grain crop produced in Roman Pannonia contains phytates, and like that of other $_4C$ plants such as maize block the uptake of iron potentially leading to anemia and CO/PH if supplemental foods are not included into the diet. It would be expected, however, that the C^{13} values of individual with significant millet incorporation be enriched. While millet consumption was a possibility, either directly or through the consumption of animals that were fed millet in the form of fodder, only one child with CO had slightly enriched C^{13} values.

Infectious disease and its relationship to iron availability could have played a role in the presence of CO/PH (see Chapter 4 for more detail). Comparisons found that while 59.37% (19/32) of

individuals with CO/PH also had periosteal bone formation, it was found that there was not a correlation between the disorders.

7.2.2 Abnormal Bone Growth – Periostitis and Infectious Disease

Epidemic disease has been postulated as playing a significant role in the decline of the later Roman Empire. Infectious disease outbreaks have been recorded by Roman historians but often suffer from a lack of detailed description of the symptoms (Stathakopoulos 2004). Furthermore, death tolls were often recorded for specific cities (Rome) or regions (North Africa), which ultimately excluded large portions of the Empire or make only general statements noting that a specific region was affected. Additionally, some of these out breaks were related to natural disasters or conflicts (warfare) which had the potential to increase stress on a population and therefore increase the risk for individuals to succumb to infection. Recently Stathakopoulos (2004) documented epidemics, famines and natural disasters based on historical documents for the late 3rd – 6th century AD, and has identified at least 23 famines and 15 epidemics occurring in Balkan region which would have included Pannonia between the 4th and 6th century. Direct impact resulting from epidemics on the Sirmium population is not known. Mention of the plague (small pox) being brought back from the east by Marcus Aurelius' in the late 2nd century to Sirmium but there is no information as to the affect it had on the population. Unfortunately, epidemics such as the ones that are discussed in the literate are likely to have significantly altered population structures of cities and regions, but these same diseases (i.e small pox) are also likely to have killed children quickly without enough time for bone and or dentition to become involved. There are some diseases (tuberculosis and leprosy), however, that will affect the skeleton leaving a type and pattern of lesions that can lead to a potential diagnosis. Evidence for

these diseases has been identified in archaeological skeletal material, through DNA extraction and macroscopic comparisons, dating to the Roman Period (Donoghue et al 2005; Lewis 2011). The mapping and description of the type distribution of lesions, while not having the ability to identify specific the pathogen responsible, this method can help to narrow down and eliminate diseases not to have likely caused the pattern of lesions. The relationship between lesions, characteristic of periostitis, and infectious disease is not clear cut, as new bone growth is also found in connection to other categories of disease including metabolic diseases and neoplasms (Resnick 2002; Weston 2008). Ortner (2003), however, notes that trauma and infection are the most common causes of periostitis.

The prevalence of periostitsis within the Sirmium collection (47.05%) was found to be similar to samples from the 3rd – 5th century in Croatia (see Slaus, 2008), close to the Adriatic Sea (48.3%) but to show a higher rate of prevalence when compare to published rates from other Continental Croatia (34.4%) for the same time period. Comparison to Roman Period Egypt (Wheeler 2010) also found that juveniles from Sirmium were found to have periosteal deposits at a higher frequency. In most cased the lower limbs and the cranial bones were affected compared to the upper limb and other region of the post-cranial skeleton.

Chapter 5 discusses the results for distribution of ABG across these age categories. Statistical analysis shows that there is a significant difference between the prevalence of affected CH2 members compared to CH1 members, which might suggest that there is an increase in survivability once individuals reach this age range (6-14 years old). This increase in prevalence for CH2 might reflect exposure to new environmental and or cultural stresses, thereby increasing

the risk of infection. Not much is currently known regarding the responsibilities of children at Sirimium but it is known from historical references that behavioral changes including apprenticeships could begin during between 6 and 14 years of age and marriage as early as between 12 and 14 years of age (Garnsey, 1999). The lack of individuals from CH1 with evidence of ABG could also reflect an inability to mount a sufficient immune response leading to death prior to the formation of new bone. Slightly more than 52% (25/48) of all individuals with periosteal bone formation exhibit systemic infection of which the 20 (80%) were from the CH2 cohort.

The etiology of the periosteal bone present on the internal surface of the crania and external surface of the post-cranial bones of most of the individuals is not determinable. There were however, some individuals in which the distribution pattern of the periosteal bone allowed for a potential diagnosis. Individual BCL268J-2, aged to approximately 13 year of age, thick active periosteal woven bone deposits were found covering much of the shaft of the right and left tibia and femur (see Figure 7.1). The thickness of the woven showed some variation but was largely consistent across the shaft of the bones with a depth of up to 2mm. In addition periosteal bone was found on the at least on metacarpal, calcaneus and ilium.

Figure 7.1 – Periosteal Bone Growth

The posterior of the right tibia exhibiting thick deposits of abnormal bone growth. Left tibia not shown here. Specimen Number: BCL268J-2

Additionally, an individual slightly older than 12 years of age exhibited periosteal bone growth affecting multiple bones including thick deposits on the surfaces of the ribs on at least one vertebra with a connection to the ribs, and on at least one metacarpal (right #1) and on the ulna. None of the affected bones showed periosteal bone deposits on the articular surfaces. On the endocranial of the orbits (frontal bone), parietal and occipital bones, lytic lesions were identified resembling those discussed by Lewis (2004). Lastly, BCL268L-3, an 11 year old, exhibited thick periosteal bone deposits affecting all of the lower limbs in addition to 3 of the 4 metatarsals.

The pattern of periosteal bone growth displayed in these three individuals is similar to other cases that have been potentially identified as being the result *Mycobacterium tuberculosis* (TB). Mays and Taylor (2002) identified two individuals with wide-spread periosteal bone deposits related to hypertrophic osteoarthopathy (HPO). One of the two individuals was found, though DNA extraction and analysis, to have TB thereby linking the macroscopic lesion distribution to a specific disease. More recently, Lewis (2011) conducted an analysis on non-adults from Roman period Britain and linked the patterns of periosteal bone growth observed on the skeletal material as potential evidence for tuberculosis.

Tuberculosis, an infectious disease caused by the bacterium *Mycobacterium tuberculosis* is transmitted is primarily through inhalation of infected droplets from one person to another or can be passed from animal to human through contaminated animal products (Cotran et al., 1999; Roberts and Buikstra, 2003). Currently TB is a major cause of child morbidity and mortality (Dixon and Roberts, 2001) and overall it is estimated that over 2 million people die as a result of TB every year (Smith, 2003). While it is clear that this disease is currently a serious concern the rate of morbidity and mortality in archaeological populations is not so clear but the lack of evidence for TB in ancient populations does not necessarily indicate that it was not a significant risk to health. In fact some have suggested that the prevalence of the disease was actually higher in ancient times (Roberts and Buikstra, 2003).

It is suggested that the spread of tuberculosis could not have become a serious health problem until people were settling is larger numbers (Roberts and Buikstra 2003). This close proximity would have allowed infection to easily pass from individual to individual. Based on

archaeological investigations at Sirmium it has been suggested that at Sirmium's peak it grew to a size of 120 hectares and approximately 60,000 people (Póczy, 1980). Apartment structures have been identified with in the city walls (Milosevic, 1971; Póczy, 1980), suggesting close living conditions. The large population living in Sirmium and the presence of a road and river system used for trade, troops and travel would be ideal for the transmission of infectious disease including tuberculosis which incidentally requires needs a large host population living in close proximity in order to survive. While no conclusive statement stating that these 3 individuals were infected with TB, the city structure, population size, along with the evidence from the skeletal material could suggest the presence of TB in the Sirmium population.

Other potential evidence for infectious disease was found in the form of abnormal bone growth on the endocranial surface of the vault bones and the internal surface of the maxillary sphenoidal sinuses. Endocranial periosteal deposits with and without hypervasuclarity, affecting this vault bones may indicate that individuals suffered from meningitis. Here as was found with long bone pathology, members of the CH2 cohort represent the largest proportion of those affected with endocranial lesions (see Chapter 4). The advanced age of the affected individuals is not likely to be related to child birth trauma. According to Lewis (2004) endocranial lesions affecting the vault bone are probably associated with inflammation or hemorrhage related to infection (i.e. TB), trauma, or metabolic diseases (i.e scurvy). Other researchers have also linked specific types of endocranial lesion with infectious disease, such as TB. Hemorrhage resulting from scurvy could also lead to the formation of abnormal bone on the internal surface of the vault bones as was by a number of researchers (see Brown and Ortner, 2009; Brickley and Ives, 2006). While not out of the question in terms of cause, there are no supporting morphological features

affecting the individuals with endocranial bone growth supporting scurvy as being the cause for these endocranial vault lesions. As Lewis noted (2004), rapid death would have likely occurred from primary meningitis not allowing enough time for periosteal bone formation. This points to, if the lesions are infectious in origin, to chronic disease rather than acute infections.

Upper respiratory Infection

Infection of the upper respiratory tract has the potential to stimulate bone growth, depositing plaques of woven bone on the internal surface of the maxillary and sphenodial sinuses. Infectious agents including *Streptococcus pneumonia* and *Staphylococcus aureus*, have been identified as microbes that can potentially lead to sinusitis. Additionally, sinusitis can be related to poor living conditions, poor air quality related to chronic exposure to smoke from indoor fires, as well as dental poor dental hygine (Roberts, 2007; Liebe-Harkort, 2012). Maxillary sinusitis in the Sirmium sample affected 18% of non-adult (see Chapter 4) which was found to be significantly less than the prevalence found in a Roman Period sample from Sweden where 45% of individuals between 1-14 years old were affected (Lieb-Harkort, 2012) which potentially suggest that non-adults in the Sirmium sample had a less stressful lifestyle. Unfortunately, there is little know regarding the specific living conditions in Sirmium other than the presence of apartment complexes and the possibility of having a population in the range of 60,000 people. Taking other pathological condition into consideration, individual with sinusitis were found to have CO, and enamel hypoplasias, slightly more than 44% and 66.66% of the time suggesting that most of these individuals exhibit evidence for having gone through periods of chronic physiological stress. This in fact may have increased the risk for developing upper respiratory infections.

Scurvy?

In addition to the ABG discussed above affecting elements of cranial vault and facial skeleton and post-cranial skeleton, porous woven bone was also found on the internal surface of the sphenoid in the basin region between the foramen rotundum and the foramen ovale. In fact, of all the cranial bones affected, the sphenoid was affected most frequently, a difference that was found not to be statistically significant except when compared to the frontal and the parietals. All other pair-wise comparisons were either not statistically significant or not quite significant. This particular type and location for ABG was first discussed in an article (see Brown and Ortner, 2011) which attributed to hemorrhage associated with childhood scurvy. More recently Gerber and Murphy (2012) have discussed this particular lesion in relationship to scurvy in an 19th century Irish population in which they found that 27% of individuals with scorbutic lesion also had ABG associated with the foramen rotudum and ovale.

In the case of the Sirmium material no other bony regions, such as the external surface of the greater wing, show convincing evidence for pathological changes associated with scurvy. Comparison between the lesions identified by Brown and Ortner (2011) affecting this particular region of the sphenoid shows no significant differences in the type and distribution to those identified in the Roman Period sample used for this thesis. These lesions could be linked to an earlier phase of scurvy prior to the characteristics that are more commonly recognized in archaeological skeletal material. As vitamin C is not produced by the body and therefore it must be incorporated into the diet, the high prevalence of this lesion, if associated with vitamin C, could indicate differential access to food sources containing Vitamin C. In addition to scurvy, infectious disease also has the potential to affect the internal surface of the cranium (see above).

Neural infection, specifically related to the maxillary nerve could lead to an inflammation of the surrounding area, affecting the endosteum and in doing so trigger the production of abnormal woven bone. This being said the relationship between individuals with periosteal bone growth on the internal surface of the sphenoid can not directly related to vitamin C deficiency or infection. The lack of correlation and the significance of the location (proximity to the brain), clearly warrants to the need for more work, specifically in regards to understanding the etiology of periosteal bone growth affecting the endocranial surface of the sphenoid.

7.3 Dental Disease

7.3.1 Hypoplasia

There are a multitude of maladies, including, cultural behaviors (weaning), nutrient deficiencies, infection, metabolic disease as well as acute trauma, which may lead to the disruption of enamel secretion and to the formation of Enamel Hypoplasia (EH), thereby relocating this particular pathological condition into the category of non-specific stress indicator (Goodman and Armelagos, 1985). The high frequency of individuals with hypoplasia (~60%) and for the number of teeth affected (~22%) is suggestive of significant stress during the period of enamel formation.

The calculated timing of defect formation indicates a few trends. First, the earliest formed defects appear largely between 2 and 4 years of age (see Chapter 5) which is often identified as the weaning period, at a frequency slightly less than 62% (124/202). If this is pushed to an earlier period as it has been suggested by Roman writers to begin at around 6 month post-natal, the percentage of hyoplastic defects increases to 71.78% (145/202). The shift to include individuals

with defects aged to have occurred between 6 months and 2 years is to recognize that weaning is a process; the incorporation of potentially lower quality food (less nutritious) and the increased risk of the introduction to pathogens, food borne or otherwise, did not start at the point when breast milk was no long a part of a diet.

Taking a closer look at this period, the majority of the defects formed during the extended weaning period (≥6 months – 4) occur between the ages of 1 and 3 (n=91), with the greatest frequency of LEH found to occur between the ages of 2 and 3 (n=74). While there is in fact a general peak of EH between 2 and 4, after the age of 3 there is an overall decreasing trend in the number of defects. The high prevalence of defects formed between the ages of 2 and 3 match with the isotopic analysis for the Sirmium sample which suggested the cessation of breast milk around the age of 3 (see Chapter 6). Enamel hypoplasia forming after the age weaning could the result of any number of possible physiological insults. In terms of post-weaning age individuals from the Sirmium material that presented hypoplasia (LEH), 20 (55.5%) individuals also had evidence for periosteal bone growth. In addition, it was also found that there was a high prevalence (70%) for cribra orbitalia in post-weaning age individuals with EH. This suggests that additional stress potentially as a consequence of dietary deficiency and or increase in pathogen load might explain the development of post-weaning EH.

The findings presented here on EH are similar to of other Roman period material. The cross comparisons between studies run into a number of difficulties as target samples, methods and reporting often differ. Taking this into consideration, the prevalence of EH at Sirmium is found to be fall in somewhere in the middle of sites like Quadrella (Bonfiglioli et al., 2003), Portus

Romae, Lucus Freoniae (Manzi et al., 1999) and the Ravenna region (Facchini et al., 2004) all showing EH frequencies between 82% and 95.2% and sites with a lower frequency of EH including Rimmi (Facchini et al., 2004), Poundbury (Brook and Smith, 2006 and Stuart-Macadam, 1985), Crotia Continental region (Slaus, 2004) with EH prevalence between 36.8% and 57.1%. While no specific etiology was offered in any of these studies a common theme suggesting weaning stress was suggested as a potential cause for EH in these populations as is suggested for the Sirmium material.

7.3.2 Caries

Unlike other dental pathology (enamel hypoplasia and calculus), evidence for caries, was with the exception of one individual was only found in members of the CH2 and ADO age cohorts. No significant difference in terms of frequency was found when all groups were compared. Overall, the prevalence of caries per tooth was found to be relatively low (3.35%) suggesting that while the diet of these individual might have be poor in some cases, it was it was not necessarily highly cariogenic. The frequency of caries for the Sirmium shows some similarities to other Roman period samples. Prowse et al. (2008) found caries (per tooth) at a rate of 3.8% with only individuals greater than 2.5 being affected. A similar pattern specifically related to a lack of individuals below 2.5 showing caries was observed in Roman Period Dorest (Redfern et al., 2012). The increase in caries related to an increase in age in the Sirmium sample as well as in other Roman period material, is likely the result of the general progressive nature of dental caries formation and the incorporation of an increase in consumption of carbohydrates. Clearly, more information on the diet in Roman Srrmium will need to be assessed before more concrete statement can be made concerning caries pattern. As with other aspects of disease discussed

above, calculation of caries frequency change over time is not possible due the small sample related to the large period in which the St. Sineros Cemetery was in use.

7.4 Large Scale Stress Events, Mortuary Practices, Prevalence of Disease – Relationships

It is difficult to associated specific stress episodes present on individual skeletons with major events affecting the Roman Empire, Pannonia, and more specifically the urban center of Sirmium. For example, historical records suggest that during the 3rd century AD, the swamps around Sirmium were filled in, primarily as a response to an increasing need for agricultural land but may have also been associated with an attempt to decrease mosquito populations, similar to attempts made by previous emperors in other parts of the Roman Empire (see Hart, 2001). Additionally, border conflicts during the 2nd century AD are thought to have created significant stress on Pannonian region (Barkóczi, 1980), which included the displacement of thousands of people and food sources (livestock) in addition to epidemic disease outbreaks. The consequence of these events as well as others later in the 4th century with the construction of the city protection trenches and walls (Milosevic, 1971; Póczy, 1980) directly address the impact on the Sirmium population. Evidence in the form of coin hoards, often associated with periods of increase turmoil, suggests some correlation with more general time periods of conflict. The Roman Empire suffered greatly during the 3rd century resulting from a variety of phenomenon but was primarily linked consequences from a period of increase warfare Due to small sample and the relatively temporally restricted boundary in which much of the non-adult material comes from, change in prevalence of disease cannot be determined, which is further confirmed by the mostly 3rd to 4th century burials for most of the adult population at Sirmium.

The majority of material excavated (adult and non-adults) from St Sineros Cemetery during the two seasons of excavation dated primarily to the 3rd and 4th century with considerable less material from the 1st, 2nd, 5th, and 6th centuries. While only a small percentage of the non-adult material can be directly associated with datable material and or was subjected to C14 analysis, it seems based on relationships to other dated material (artifacts associated with adults), that the majority of the material utilized for this dissertation was from the 3rd to 4th century.

Chapter 3 discussed the distribution of those individuals that were found to have been buried in grave with and without additional mortuary structures as well as those non-adults found with associated grave goods and Chapter 4 presented the results for bone and dental disease with in the sample population. Evidence for disease was found in 85% (46/54) with dental pathology found in 94.4% of individuals which was, in both cases significantly higher than the prevalence for those individuals that were found in disturbed burials or unknown burial types. This may indicate a difference in status in that those children with evidence for pathology obviously survived long enough for the disease to affect bone, thereby suggesting a better immune system which might be linked to better quality foods, or less acute stressors or families that could afford to pay for health care. Furthermore, the fact that they were interred in indefinable graves may indicate that the families could afford or had access to a burial plot while those that did not show proper grave outlines were deposited in unmarked graves that were later disturbed.

Exposure to diseases that might lead to rapid death are often those that do not leave any evidence on bone or dental material. If we are to approach the differences identified above, as the result of lower status living standards and poverty, children may have been at higher risk for poor

nutrition and or exposure to pathogens in addition to the inability, once stressed to fend off or recover from these episodes of stress. Alternative reasoning for the difference identified above might simply be related to fewer bones being recovered from these individuals due to the state of preservation and disturbance so, caution is needed when interpreting the differences between these groups related to graves and disease.

When only those individuals with evidence for artifacts are taken into consideration, it was found that those with grave goods were found to be exclusively buried in identified graves with or with additional grave structures. These individuals represented 31.48% (17/54) of all individuals with evidence for grave shafts. Within this group, 88.23% and 100% of individuals exhibited bone and dental pathology, respectively suggesting that there is a correlation between burials with artifacts and pathology. A similar frequency was observed when those with additional mortuary structures and artifacts where compared to pathology. Here, 85.71% (6/7) were found with grave structures, artifacts and pathology, all of which exhibited evidence for chronic stress in the form of CO, systemic infection, and or hyoplastic defects. The relationship between pathology and mortuary behavior may again suggest that children and other non-adults of higher status, based on the presence of grave goods and mortuary structure, may have had a better chance of survival compared to other groups. The lack of grave goods, associated with majority of individuals with in Sirmium sample, may indicate a difference in mortuary ritual (see Norman, 2002).

Individuals comprising the non-adults from Roman Sirmium displayed a high prevalence for bone and dental pathology that can be interpreted in a variety ways. Large scale stress events on an Empire-scale, regional and or local scale most likely played a role in the patterns and

individual examples of the consequences of physiological stress exhibited on the bones and dental material of these individuals.

The largest age group represented from the Sirmium material was comprised of individuals from the CH2 cohort (6-14 years old) which, was unexpected as these individuals survived through the most risky period of early development only to perish in between before 15 years of age. Successive bouts of disease and stress, while it is evident that many survived multiple episodes of stress, may have played a role in weakening or limiting future responses to prolonged stress allowing them to reach an older age. In order to more fully understand both the individual risks and the broader more general risks these individuals were exposed to, diet, social structure, population dynamics (cultural and genetic) and environment of the Sirmium population needs to be explored using a holistic research approach.

Chapter 8

Conclusion and Future Directions

8.1 Conclusion

Between the 1st and 6th century AD the Roman Empire expanded to it greatest geographic extent, pushing its boundaries far into the east and the edge of the Atlantic. These 600 years also witnessed the splintering of the Empire into the Eastern and Western Empire with the fall of the Western half in the 5th century. Prior, beginning in the late 2nd century AD and climaxing in the 3rd century, the Empire was in a grasp of crisis that touched all segments of Roman life and society, including economics, military, ruling class, commoners, and the overall culture of all regions of the Roman Empire. This crisis is likely to have had roots in warfare and invasion during the 3rd century, but was also influenced by earlier phenomenon such as warfare and epidemics. Periods of prosperity were not unfound, but were ultimately interrupted by periods of unrest.

The city of Sirmium, which found its Roman beginnings in the mid-1st century AD, based on archaeological evidence was affected to varying degrees by environmental, social and biological stressors, over the approximately 600 years of existence as a Roman stronghold. These phenomena, often intimately linked, would have directly affected the population of Sirmium and because of the fragility of specific age groups of non-adults (i.e individuals less than 5 years of age) may have had a significant impact on their morbidity and mortality rates. While the majority of skeletal material used for this dissertation was excavated from 3rd and 4th century levels of the cemetery, there are too few to make definitive statements relating morbidity and mortality to temporally related periods of social, economic or environmental stress.

The results of dietary analyses using stable isotopes offer some information related to behavior. Differences between adult and non-adult diet were identified, specifically associated with weaning age and directly post weaning age individuals. Differences were also identified within the non-adults subjected to isotopic analysis. Some of the inconsistencies in food consumption are attributed to breast-feeding practices; others however, are likely to be directly related to differential diet. It is difficult to identify specific a factor or group factors related to the root of these differences. Diet is regulated by various controlling elements, including environment, individual biology (allergies), and cultural practices and as such pinning down a single cause is almost impossible. It is possible, however, that during periods of elevated social stress, poorer quality foods (i.e millet) may have been consumed by some of the individuals as related to the elevated C13 values. In addition, clear evidence for the weaning period was identified suggesting that cessation of breast milk occurred around 3 years of age. Based on the sample analyzed, using stable carbon and nitrogen isotopes, the weaning period was similar to other regions of the Roman Empire, pointing to cross regional similarities in cultural behavior.

8.2 Future Directions

This collection holds great potential for future analysis specifically related to non-adults. A complete study in which dietary isotopic data is collected for all non-adults in addition to a larger sample of adults would significantly add to the our understanding of dietary behavior (weaning and post-weaning diet) and cultural practices. Historical records and artifact data suggest that the Sirmium population was a mixture of individuals of different ancestry. Migration studies using strontium and oxygen isotopes would help to supplement archaeological and historical data

thereby painting a more comprehensive picture of the biological and cultural demographics of Sirmium.

In addition to a larger project using stable isotopes, a smaller project with a focus on aDNA specifically targeting non-adults to look at the distribution of males and females present in the collection. This project would significantly contribute to our understanding, disease patterns, dietary patterns, and mortuary practices at Sirmium. As discussed previously, significant consideration regarding the ethics of aDNA work would be of primary concern prior to the start of any destructive analyses. Lastly, while this thesis targeted non-adults the addition of the data collected from the adult segment of the population in relationship to disease patterns and survivability would be a natural next step for this collection and research.

Appendix A

Sirmium Sample – Non-Adults Numerical Age

SubSP#	AGE CATEGORY	AGE NUMERIC
SL2610-C-5-168-S101-1	CH1	2.67
SL2610-C-9-172-S100-1	CH2	7.24
SL2610-C-CS25B-DENT-1	CH1	4.50
SL2610-F-1-173-B3A-1	CH1	5.75
SL2610-F-CS4B-HF-1	FET	37.2 W
SL2610-F-NA-NA-B2C-1	CH2	7.64
SL2610-F-NA-NA-B3D1-1	CH2	6.50
SL2610-G-CS11B-HF-1	PER	40 W
SL2610-G-CS5B-HF-1	NEO	40.5 W
SL2610-H-2-180-B8J-1	ADO	16.00
SL2610-H-7-184-B17A-1	OTH	0.18
SL2610-H-CS18-DENT-1	CH1	5.50
SL2610-L-2-188-B7E-1	CH1	5.25
SL2610-M-11-199-S58-1	CH2	12.60
SL2610-M-13-201-S102-1	CH2	7.03
SL2610-M-7-195-B4D-1	CH1	1.75
SL2610-M-CS18-DENT-1	CH2	9.00
SL2610-M-CS38B-HF-1	FET	32 W
SL2610-M-NA-NA-B2A-1	CH1	3.00
SL2610-M-NA-NA-B2F-1	CH1	3.00
SL2610-M-NA-NA-B3B2-1	CH2	6.25
SL2610-M-NA-NA-B3H-1	NEO	0.08
SL2610-M-NA-NA-B5F-1	CH1	5.25
SL2610-M-NA-NA-B6A-1	CH2	7.50
SL2610-M-NA-NA-S117-1	ADO	15.83
SL2611-EF-EXT-1-NA-S116-1	CH2	6.00
SL2611-F-11-216-B7B-1	CH2	11.75
SL2611-F-CS4-DENT-1	CH2	8.50
SL2611-J-3-224-B7C-1	CH2	14.25
SL2611-J-4-225-S106-1	CH2	9.45
SL2611-J-5-225-B4B-2	CH1	1.75
SL2611-J-8-228-B1K-1	CH2	9.75
SL2611-J-NA-NA-B7D-1	CH2	9.75
SL2611-M-2-234-B5B-1	CH2	7.31
SL2611-M-CS27B-HF-1	PER	40.5W
SL2611-M-CS5B-HF-1	PER	40.83 W
SL2611-N-9-251-S110-1	CH2	11.49
SL2611-N-EXT-4-254-B1L-1	CH1	2.13
SL2612A-E-EXT-12-318-S114-1	CH2	9.90
SL2612A-E-EXT-23-325-7M-1	CH2	12.55
SL2612A-E-EXT-CS144B-DENT-1	CH2	11.1
SL2612A-E-EXT-CS26A-HF-1	FET	39.37 W
SL2612A-E-EXT-CS82A-HF-1	FET	33.21 W

SubSP#	AGE CATEGORY	AGE NUMERIC
SL2612A-E-EXT-NA-NA-B7I-1	CH2	10.50
SL2612A-E-EXT-NA-NA-B8O-1	CH1	1.19
SL2612A-E-EXT-NA-NA-B8P-1	CH2	6.83
SL2612A-NA-NA-B8L-1	CH1	2.5
SL2612A-NA-NA-B9A-1	CH1	3.38
SL2612A-NW-4-289-S115-2	CH2	10.75
SL2612A-NW-QUAD-1-286-S109-1	CH2	7.38
SL2612A-NW-QUAD-15-298-7J-1	CH2	6.00
SL2612A-NW-QUAD-3-288-S115-1	CH2	7.50
SL2612A-SE-QUAD-CS8-HF-1	FET	39.02 W
SL2612A-SE-QUAD-NA-NA-10E-1	CH2	9.93
SL2612A-SW-QUAD-5-290-S112-1	CH1	5.00
SL2612A-SW-QUAD-NA-NA-S113-1	CH2	11.31
SL2612-QUAD 28-19-275-B1O-1	CH1	2.13
SL2612-QUAD 6-22-277-B6E-1	INF	0.25
SL261-G-18-NA-B24K-1	CH2	6.70
SL261-G-23-3-S122-1	ADO	16.00
SL261-G-6-NA-B35D-1	CH2	10.50
SL261-H-NA-NA-B35A-1	ADO	15.00
SL261-J-1-NA-B35B-1	CH2	13.48
SL262-H-8-24-S51-1	CH2	11.25
SL263-G-13-41-B21G-1	CH2	10.33
SL263-G-14C-45-S111-1	CH2	13.41
SL263-G-14E-47-B11F-1	CH2	13.13
SL263-G-3-34-B13A-1	CH1	4.00
SL264-J-58-57-B13D-1	CH2	10.80
SL264-J-NA-NA-B12C-1	CH2	13.50
SL264-J-NA-NA-B21E-1	CH2	6.00
SL264-J-NA-NA-S60E-1	CH1	4.75
SL265-K-71-65-S105-1	CH2	12.46
SL265-K-NA-NA-B24F-1	CH2	8.50
SL265-K-NA-NA-B2G-1	CH2	10.00
SL265-L-NA-NA-B6B-1	CH1	3.75
SL267-F-10-83-B8D-1	CH2	6.20
SL267-F-14-85-S108-1	ADO	16.13
SL267-F-9-81-B8B-1	ADO	15.00
SL267-G-32-89-S39A-1	CH2	13.75
SL267-G-34-91-B11B-1	CH1	2.25
SL267-G-35-92-B21I-1	CH2	6.08
SL267-G-40-95-B5E-1	CH2	13.50
SL267-L-NA-NA-B4A2-1	CH2	6.50
SL267-N-NA-NA-B15D-1	CH2	7.50
SL268-F-5-115-B19D-1	CH2	13.80
SL268-J-67-130-S107	CH2	13.10
SL268-J-NA-NA-B21K-1	CH2	6.68
SL268-L-48-136-B20B-1	CH2	13.30
SL268-L-52-137-S56-2	CH2	11.00

SubSP#	AGE CATEGORY	AGE NUMERIC
SL268-L-52-137-S56-3	FET	31.78W
SL268-N-EXT-NA-NA-B19B-1	CH2	10.00
SL268-N-NA-NA-B17B-1	CH2	9.68
SL268-N-NA-NA-B19C-1	ADO	15.00
SL268-N-NA-NA-B20A-1	CH1	1.00
SL269-N-EXT-29-150-S103-1	CH2	7.80
SL269-N-EXT-31-152-S104-1	CH2	8.66
SL269-N-EXT-32-153-S118-1	ADO	16.13
SL269-N-EXT-32-NA-S27F-1	CH2	8.00
SL269-N-EXT-38-NA-B3G-1	CH2	12.06
SL269-N-EXT-NA-NA-B21A-1	CH2	7.50
SL269-N-EXT-NA-NA-B23B-1	CH2	11.60

Appendix B

Sirmium Sample – Non-Adults Long Bone Measurements

SubSP#	BONE	SIDE	M1 (mm)
SL2610-C-5-168-S101-1	HUM	Left	130.1
SL2610-C-5-168-S101-1	RAD	Right	100
SL2610-C-9-172-S100-1	FEM	Left	256
SL2610-C-9-172-S100-1	FEM	Right	257
SL2610-C-9-172-S100-1	HUM	Left	183
SL2610-C-9-172-S100-1	HUM	Right	186
SL2610-C-9-172-S100-1	ULN	Left	158
SL2610-C-9-172-S100-1	RAD	Right	141
SL2610-C-9-172-S100-1	RAD	Left	139
SL2610-F-1-173-B3A-1	FIB	Right	210
SL2610-F-1-173-B3A-1	FEM	Right	206
SL2610-F-1-173-B3A-1	RAD	Right	139.03
SL2610-F-1-173-B3A-1	ULN	Right	149.98
SL2610-F-NA-NA-B3D1-1	TIB	Left	226
SL2610-F-CS4B-HF-1	TIB	Left	61.07
SL2610-G-CS5B-HF-1	TIB	Left	69.25
SL2610-G-CS11B-HF-1	FEM	Left	76.7
SL2610-H-2-180-B8J-1	RAD	Left	212
SL2610-H-2-180-B8J-1	TIB	Right	315.5
SL2610-H-7-184-B17A-1	FEM	Left	84.91
SL2610-H-7-184-B17A-1	FEM	Right	85.1
SL2610-H-7-184-B17A-1	TIB	Left	70.56
SL2610-H-7-184-B17A-1	TIB	Right	69.75
SL2610-H-7-184-B17A-1	HUM	Right	71.84
SL2610-H-7-184-B17A-1	ULN	Right	63.34
SL2610-H-7-184-B17A-1	ULN	Left	65.05
SL2610-H-7-184-B17A-1	RAD	Right	57.76
SL2610-H-7-184-B17A-1	RAD	Left	57.75
SL2610-L-2-188-B7E-1	TIB	Left	208.5
SL2610-L-2-188-B7E-1	TIB	Right	208
SL2610-L-2-188-B7E-1	FIB	Left	203
SL2610-L-2-188-B7E-1	FIB	Right	202
SL2610-M-NA-NA-B3H-1	FIB	Left	66.59
SL2610-M-CS38B-HF-1	FEM	Left	55.77
SL2610-M-NA-NA-B5F-1	FEM	Right	252
SL2610-M-NA-NA-B3B2-1	FEM	Left	278.5
SL2610-M-NA-NA-B3B2-1	FEM	Right	278.5
SL2610-M-NA-NA-B3B2-1	TIB	Right	221.5
SL2610-M-NA-NA-B3B2-1	FIB	Right	207
SL2610-M-NA-NA-B3B2-1	HUM	Left	190
SL2610-M-NA-NA-B3B2-1	RAD	Left	144
SL2610-M-NA-NA-B3B2-1	ULN	Left	157.5
SL2610-M-13-201-S102-1	HUM	Left	180

SubSP#	BONE	SIDE	M1 (mm)
SL2610-M-13-201-S102-1	HUM	Right	181
SL2610-M-13-201-S102-1	RAD	Left	132
SL2610-M-13-201-S102-1	RAD	Right	132
SL2610-M-13-201-S102-1	ULN	Left	147
SL2610-M-13-201-S102-1	ULN	Right	148
SL2610-M-NA-NA-B6A-1	TIB	Right	255
SL2610-M-11-199-S58-1	HUM	Right	236
SL2610-M-11-199-S58-1	RAD	Right	186.5
SL2610-M-11-199-S58-1	ULN	Left	200
SL2611-EF-EXT-1-NA-S116-1	HUM	Left	167
SL2611-EF-EXT-1-NA-S116-1	ULN	Left	119
SL2611-EF-EXT-1-NA-S116-1	FEM	Left	229
SL2611-EF-EXT-1-NA-S116-1	TIB	Left	185
SL2611-F-11-216-B7B-1	FEM	Left	385
SL2611-F-11-216-B7B-1	RAD	Left	207
SL2611-F-11-216-B7B-1	ULN	Left	231
SL2611-J-4-225-S106-1	HUM	Right	218
SL2611-J-4-225-S106-1	HUM	Left	207
SL2611-J-4-225-S106-1	RAD	Right	157
SL2611-J-4-225-S106-1	RAD	Left	154
SL2611-J-4-225-S106-1	FEM	Left	294
SL2611-J-4-225-S106-1	TIB	Right	234
SL2611-J-4-225-S106-1	TIB	Left	232
SL2611-J-8-228-B1K-1	TIB	Right	298
SL2611-J-8-228-B1K-1	FIB	Left	264
SL2611-J-5-225-B4B-2	RAD	Right	76.46
SL2611-J-5-225-B4B-2	ULN	Right	82.91
SL2611-J-5-225-B4B-2	TIB	Right	100.64
SL2611-M-2-234-B5B-1	HUM	Left	208
SL2611-M-2-234-B5B-1	RAD	Left	166
SL2611-M-2-234-B5B-1	FEM	Right	310
SL2611-M-2-234-B5B-1	TIB	Right	248
SL2611-M-2-234-B5B-1	TIB	Left	249
SL2611-M-CS5B-HF-1	FEM	Left	82.57
SL2611-M-CS27B-HF-1	FEM	Right	76.27
SL2611-N-9-251-S110-1	RAD	Left	188.5
SL2611-N-9-251-S110-1	ULN	Left	208
SL2611-N-9-251-S110-1	FEM	Left	355.5
SL2611-N-9-251-S110-1	TIB	Right	294
SL2611-N-EXT-4-254-B1L-1	HUM	Left	109.4
SL2612A-NA-NA-B9A-1	ULN	Right	117.5
SL2612A-NA-NA-B9A-1	HUM	Right	139
SL2612A-NA-NA-B9A-1	FEM	Right	175
SL2612A-E-EXT-NA-NA-B8O-1	FEM	Right	122.22
SL2612A-E-EXT-NA-NA-B8O-1	FEM	Left	123.85
SL2612A-E-EXT-NA-NA-B8P-1	TIB	Right	225
SL2612A-E-EXT-NA-NA-B8P-1	TIB	Left	223

SubSP#	BONE	SIDE	M1 (mm)
SL2612A-E-EXT-NA-NA-B8P-1	FEM	Left	268
SL2612A-E-EXT-12-318-S114-1	HUM	Right	231
SL2612A-E-EXT-12-318-S114-1	HUM	Left	224.5
SL2612A-E-EXT-12-318-S114-1	ULN	Left	199
SL2612A-E-EXT-12-318-S114-1	FEM	Right	336
SL2612A-E-EXT-12-318-S114-1	FEM	Left	338
SL2612A-E-EXT-CS26A-HF-1	TIB	Left	66.32
SL2612A-E-EXT-CS82A-HF-1	HUM	Left	53.57
SL2612A-NW-QUAD-1-286-S109-1	ULN	Right	167
SL2612A-NW-QUAD-1-286-S109-1	FEM	Right	288
SL2612A-NW-QUAD-1-286-S109-1	TIB	Right	233
SL2612A-NW-QUAD-1-286-S109-1	TIB	Left	231
SL2612A-NW-QUAD-3-288-S115-1	HUM	Left	212
SL2612A-NW-QUAD-3-288-S115-1	ULN	Right	175
SL2612A-NW-QUAD-3-288-S115-1	ULN	Left	172.5
SL2612A-NW-QUAD-3-288-S115-1	FEM	Right	302.5
SL2612A-NW-QUAD-3-288-S115-1	FEM	Left	300.5
SL2612A-NW-QUAD-3-288-S115-1	TIB	Left	239.5
SL2612A-NW-4-289-S115-2	HUM	Left	239.5
SL2612A-NW-4-289-S115-2	ULN	Left	207
SL2612A-NW-4-289-S115-2	FEM	Right	348
SL2612A-SE-QUAD-CS8-HF-1	HUM	Left	66.24
SL2612A-SW-QUAD-5-290-S112-1	HUM	Right	154
SL2612A-SW-QUAD-5-290-S112-1	HUM	Left	153
SL2612A-SW-QUAD-5-290-S112-1	RAD	Right	120.5
SL2612A-SW-QUAD-NA-NA-S113-1	ULN	Left	172
SL261-G-6-NA-B35D-1	FEM	Left	332
SL262-H-8-24-S51-1	RAD	Right	198.5
SL262-H-8-24-S51-1	FEM	Right	372
SL263-G-3-34-B13A-1	HUM	Right	161
SL263-G-3-34-B13A-1	FEM	Right	221.5
SL263-G-13-41-B21G-1	RAD	Right	188
SL263-G-13-41-B21G-1	FEM	Right	338
SL263-G-13-41-B21G-1	ULN	Right	202
SL263-G-14C-45-S111-1	RAD	Right	213
SL263-G-14C-45-S111-1	FEM	Left	419
SL263-G-14C-45-S111-1	FEM	Right	417
SL263-G-14C-45-S111-1	TIB	Left	323
SL263-G-14C-45-S111-1	FIB	Left	317
SL263-G-14E-47-B11F-1	ULN	Right	236
SL263-G-14E-47-B11F-1	RAD	Right	211
SL264-J-58-57-B13D-1	FEM	Left	311
SL264-J-58-57-B13D-1	HUM	Right	229.5
SL264-J-NA-NA-S60E-1	FEM	Right	236
SL265-K-71-65-S105	HUM	Left	205
SL265-L-NA-NA-B6B-1	TIB	Right	178
SL267-F-14-85-S108-1	HUM	Left	289

SubSP#	BONE	SIDE	M1 (mm)
SL267-F-14-85-S108-1	ULN	Right	239.5
SL267-F-14-85-S108-1	ULN	Left	233
SL267-F-14-85-S108-1	RAD	Right	224.5
SL267-F-14-85-S108-1	FEM	Left	416
SL267-F-14-85-S108-1	TIB	Right	353
SL267-F-14-85-S108-1	TIB	Left	355
SL267-G-35-92-B21I-1	ULN	Left	139
SL267-G-32-89-S39A-1	HUM	Left	285.5
SL267-G-34-91-B11B-1	FIB	Left	82
SL267-G-34-91-B11B-1	FIB	Right	71
SL267-G-34-91-B11B-1	TIB	Left	105.5
SL267-G-34-91-B11B-1	TIB	Right	90.5
SL267-NA-NA-B4A2-1	FEM	Right	203
SL268-L-52-137-S56-3	HUM	Left	50.54
SL268-N-NA-NA-B20A-1	HUM	Left	100.77
SL268-N-NA-NA-B20A-1	HUM	Right	81.31
SL269-N-EXT-31-152-S104-1	HUM	Right	193
SL269-N-EXT-32-153-S118-1	RAD	Right	215
SL269-N-EXT-32-153-S118-1	ULN	Right	241
SL269-N-EXT-32-153-S118-1	FEM	Left	381
SL269-N-EXT-32-153-S118-1	TIB	Right	318.5
SL269-N-EXT-NA-NA-B21A-1	TIB	Left	236
SL269-N-EXT-NA-NA-B21A-1	FEM	Right	307
SL269-N-EXT-38-NA-B3G-1	TIB	Right	275
SL269-N-EXT-38-NA-B3G-1	TIB	Left	274
SL269-N-EXT-38-NA-B3G-1	FIB	Left	261.5

Appendix C

SUERC – Isotope Laboratory Protocol

According to the protocol used by this laboratory, bone samples were first cleaned and placed in molar HCl in order to demineralize. Following demineralization, the collagen was washed, and when necessary .5 M HCl was added to shift the pH to 3. Samples were then heated to 80°C, and cooled and ultimately freeze dried at which time they were subjected to combustion according to the methods of Vandeputte et al (1996). Extraction of CO_2 was based on Slota et al (1987) and the C13/C14 ratio was measured on a single stage mass spectrometer according to Freeman et al (2010).

Appendix D

Isotope SUERC Laboratory Code and Bone Selection

SubSP#	AGE	LAB CODE	BONE	C13	N15	MOL	C14
SL2610C-5-168-S101-1	2.67	N1016	HUM	-18.8	11.9	3.5	NO
SL2610-C-9-172-S100-1	7.24	SUERC-16003 (GU15830)	RAD	-19.2	9.8	3.5	YES
SL2610-H-10-26-S46-1	37.2	N1027	RAD	-18.6	10.6	3.4	NO
SL2610-H-2-180-B8J-1	16	SUERC-15995 (GU-15826)	TIB	-18.9	10.2	3.4	YES
SL2610-H-7-184-B17A-1	.5	N1000	HUM	-18.6	12.7	3.3	NO
SL2610-M-11-199-S58-1	12	N1029	HUM	-18.4	10.3	3.3	NO
SL2610-M-13-201-S102-1	7.03	SUERC-8365 (GU-13517)	HUM	-18.5	9.9	3.2	YES
SL2610-M-7-195-B4D-1	1.5	N1007	HUM	-19.4	10.7	3.3	NO
SL2610-M-NA-NA-B3B2-1	6.25	SUERC-8370 (GU-13519)	TIB	-18.7	9.5	3.2	YES
SL2610-M-NA-NA-B3H-1	.083	N1005	FIB	-19.6	11.1	3.3	NO
SL2611-EF-EXT-1-NA-S116-1	6.76	N1025	TIB	-18.6	9.8	3.2	NO
SL2611-F-11-216-B7B-1	11.75	N1021	FIB	-19.7	10.0	3.3	NO
SL2611-J-4-225-S106-1	9.28	SUERC-8364 (GU-13516)	RAD	-18.6	10.4	3.1	YES
SL2611-J-5-225-B4B-2	1.75	N1006	HUM	-18.8	12.1	3.4	NO
SL2611-M-2-234-B5B-1	7.75	N1008	ULN	-16.5	12.3	3.4	NO
SL2611-N-9-251-S110-1	12	SUERC-16001 (GU-15828)	HUM	-19.5	10.3	3.3	YES
SL2611-N-EXT-4-254-B1L-1	2.5	N1003	HUM	-19.4	10.0	3.4	NO
SL2612A-E-12-318-S114-1	9	N1024	RAD	-19.5	6.8	3.5	NO
SL2612A-E-23-325-7M-1	11.25	N1011	HUM	-20.3	9.3	3.3	NO
SL2612A-E-EXT-NA-NA-B8O-1	1.19	N1014	HUM	-18.5	13.9	3.4	NO
SL2612A-NA-NA-B9A-1	3.38	N1020	HUM	-20.2	9.9	3.3	NO
SL2612A-NW-QUAD-1-286-S109-1	6.75	SUERC-16996 (GU-15827)	TIB	-19.3	8.3	3.5	YES
SL2612A-NW-QUAD-15-298-7J-1	6	N1010	CLA	-19.1	10.4	3.2	NO
SL2612A-SW-QUAD-5-290-S112-1	4.70	N1022	HUM	-19.9	9.8	3.3	NO
SL2612A-SW-QUAD-NA-NA-S113-1	11.31	N1023	RAD	-18.3	10.6	3.3	NO
SL2612-QUAD 6-22-277-B6E-1	.125	N1009	FEM	-18.7	12.9	3.4	NO
SL263-G-14D-46-S50-1	44	N1028	HUM	-19.0	9.0	3.4	NO
SL265-K-71-65-S105-1	12.46	N1018	HUM	-19.0	10.6	3.3	NO
SL267-F-10-83-B8D-1	6.2	N1012	HUM	-16.9	9.3	3.4	NO
SL267-F-14-85-S108-1	16.13	N1019	HUM	-19.3	9.5	3.2	NO
SL267-G-35-92-B21I-1	6.49	N1013	PAR	-16.2	9.9	3.4	NO
SL268-F-5-115-B19D	13.8	N1026	PAR	-20.2	8.2	3.3	NO
SL268-J-67-130-S107-1	7	SUERC-8366 (GU-13518)	TIB	-19.0	9.2	3.2	YES
SL268-L-60-138-B18A-1	22.5	N1001	HUM	-19.8	9.7	3.3	NO
SL268-M-21-140-B18E-1	24.25	N1002	HUM	-19.6	11.6	3.4	NO
SL268-N-NA-NA-B20A-1	1	N1004	HUM	-16.9	12.8	3.3	NO
SL269-N-EXT-31-152-S104-1	9	N1017	HUM	-17.5	10.1	3.5	NO
SL269-N-EXT-32-153-S118-1	16.13	SUERC-16002 (GU-15829)	HUM	-19.7	10.1	4.7	YES
SL269-N-EXT-34-155-S36-1	41.06	N1015	RAD	-18.5	10.1	3.4	NO

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