BIOARCHAEOLOGY OF URBAN VERSUS RURAL HISTORIC NORTH CAROLINA FAMILY CEMETERIES

By

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July, 2023

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Major Department: Anthropology

The urban U.S. in the 18th and 19th centuries often is characterized by poor childhood health due to high population density, poor sanitary conditions, and high levels of pollution. While bioarcheological investigations have identified poor nutrition and high activity levels of enslaved populations in the Southeastern U.S., the impact of urban environments in this predominantly agricultural, non-industrialized region remains relatively understudied. This investigation focuses on how endogenous and exogenous factors impacted subadult morbidity and mortality patterns of two families from the urban and rural southeastern U.S. during the 18th and 19th centuries. Skeletal and dental lesions associated with disease and malnutrition were documented in a minimum of 13 commingled subadults from the Rhem family vault, located in New Bern, North Carolina. These variables were compared to a contemporary sample of 4 subadults from the Foscue burial vault, built by a land-owning family in rural eastern North Carolina, to identify rural and urban health differences. Greater evidence of pathologies was visible in the Rhem infants and children compared to the lack of stressors in the Foscue neonates. These patterns may reflect the impact of weaning stressors and deleterious urban conditions on the health of the Rhem subadults, which their high status failed to buffer. In contrast, the Foscue neonates were more susceptible to childbirth complications and demonstrated no significant

pathologies possibly due to buffering via maternal passive immunity. This evidence highlights the complexity of urban and rural health and the significance of intrauterine and early childhood environments on subsequent health outcomes.

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A Thesis

Presented to the Faculty of the Department of Anthropology

East Carolina University

In Partial Fulfillment of the Requirements for the Degree

Master of Arts, Anthropology

By

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July, 2023

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ACKNOWLEDGEMENTS

I would first like to thank Mr. David French and Mr. Michael Miller for allowing the ECU department to excavate the Rhem Vault and providing a unique opportunity for bioarchaeological research. I would also like to thank my advisor, Dr. Megan Perry for her vital guidance and support during every stage of this project. Additional thanks to Dr. Charles Ewen and Dr. Ryan Schacht for their valuable support and insight. Several ECU students also provided necessary assistance during this process including Ceara Nicholson and McClean Pink for their aid in the field and the lab. Special thanks to my co-partner on this project, Jalynn Stewart who took charge of research on the coffin artifacts and helped in every single stage of the process. Finally, I would like to thank my family and friends for their endless encouragement and love throughout this entire project.

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CHAPTER ONE:

INTRODUCTION

The eighteenth and nineteenth centuries were a period of increasing industrialization and rapid urbanization in the United States. Urban centers during this period have been typically characterized by high population density and overcrowding, severe air pollution, contaminated food and water sources, and inadequate sewage disposal, resulting in extensive transmission of infectious disease that threatened the health and lifestyles of city residents. In contrast, it is generally considered that rural areas offered fresh, unpolluted air, adequate sunlight exposure, diversified diets, and lower population size which were conducive for greater health outcomes (Brunton, 2013; Page, 1851). However, this over-simplified "urban-rural dichotomy" of health risks masks the heterogeneity within and between contexts as well as the effects of sociocultural practices and socioeconomic status. Populous cities and rural plantation settlements in eastern North Carolina during this period represent the diversity within each respective context that will help to illuminate differential health and mortality risks in urban-rural environments. Two branches of the same family, one living in the local industrial center of New Bern, North Carolina and another owning land and working it through the labor of enslaved individuals near Pollocksville, North Carolina will provide a comparative perspective of this dichotomy.

During the 18th- 19th century, the Rhem family were prominent members of New Bern. They engaged in various economic and political ventures through operation of industrial factories and commercial farming as well as serving on local government committees, which established their wealth and status in society ("Death of Joseph L. Rhem", 1901; "Preliminary Steps Towards", 1859). The family remains were interred in the local family vault in Cedar Grove Cemetery with burials ranging from the mid-19th to late 20th century (*Joseph L Rhem*

Family Bible, 2020/1860). There has been recent interest in the vault and family history associated with the burials. The descendants of the family, David French and Michael Miller contacted the ECU Department of Anthropology in 2020 to remove the vault contents for historical renovations, and thus, a field season was conducted in June of that year to remove the coffins and excavate the remaining floor deposits.

Residing in the countryside near Trenton and Pollocksville, NC, the Foscues were an elite planter family during the 18th-19th centuries. Of particular interest, one of the Foscue members, Christiana “Kitty” Rhem is the paternal aunt of Joseph L. Rhem, Sr, indicating a familial relationship between the groups (Perry et al., in press). Seeman (2011) and colleagues excavated the remains located in the family burial vault and developed osteobiographies of recovered individuals based on construction of biological profiles and assessment of skeletal stressors. This current study is based on the macroscopic analysis of the Rhem and Foscue subadult skeletal remains to understand differential patterns of morbidity and mortality in urban and rural environments in 18th-19th century eastern North Carolina. This research examines the influence of endogenous and exogenous factors on mortality and morbidity in this context through analysis of historical and bioarchaeological literature of environmental conditions, obstetric practices, and infant and child caretaking practices including weaning. This investigation also explores the concept of the mother-infant nexus through analyzing evidence of subadult skeletal stressors in relation to maternal stress and health especially during fetal and infant development. These stressors during early periods of growth and development reflect the intergenerational transmission of health such as maternal malnutrition and infection hindering fetal/infant growth and development.

Intellectual merit

There is limited bioarchaeological literature of urban-rural comparative studies in the United Studies (Blakely & Beck, 1982; Davidson et al., 2002; Franklin & Wilson, 2020). Furthermore, most studies focusing on historical U.S. communities do not center on morbidity and mortality analysis of high-status populations, which can enrich knowledge of health disparities related to social stratification across environmental contexts. Exploration of the mother-infant nexus in this investigation can also reveal the interconnected relationship of health and sociocultural dynamics on growth and development especially during a historical period of poor sanitation and rampant disease. Utilizing historical documents and genealogical information, this research contextualizes evidence of skeletal stressors from metabolic disease and infection to highlight health effects of urbanization, weaning practices, and breastfeeding. Finally, collaboration with descendent family members is significant for uncovering genealogical information to understand their historical background. David French and Michael Miller provided transcriptions of the family bible and primary sources related to their local history which were crucial for this study.

Broader impacts

Bioarchaeological investigations of urban-rural environments shed light on health disparities related to accessibility of 18th-19th century healthcare services, quality of living and working conditions, dietary diversity, and other factors that continue to impact even modern populations. Skeletal analysis of metabolic disease and infection in subadults highlights if infants and children experienced malnutrition while in utero and/or during later periods of growth and development. This evidence can also aid in inferring the status of maternal health, and general health of the population to reveal quality of lifestyles. Furthermore, this perspective of the mother-infant nexus emphasizes that early life adversities can result in long-term health consequences into adulthood, and that health and disease are not restricted to an individual biography but instead, are inherited across generations.

CHAPTER TWO:

BACKGROUND

The rise of New Bern as an industrial center during the 18th and 19th centuries likely meant its population faced different health risks compared to their more rural counterparts. Here the historical background of the region is discussed, along with the family histories and burial contexts of the Rhems and Foscues, the two families focused on in this study. In addition, it covers how bioarchaeology can be used to explore morbidity and mortality in urban and rural environments, focusing on infant and childhood health and the intricate health dynamics of the mother-infant nexus. Overall, this research aims to examine skeletal evidence of physiological stressors, including nutritional deficiencies and infectious disease, to understand the differential morbidity and mortality patterns in urban and rural environments in 18th-19th century eastern North Carolina.

Historical background

The city of New Bern was founded in the 18th century between the Neuse and Trent Rivers and served as a major commercial hub in eastern North Carolina (Watson, 1987). New Bern is the county seat of Craven County and served as the original capital of the state in the late 18th century (Watson, 1987). Known as “Old Athens” or the “Athens of North Carolina” in the early 19th century, New Bern had a diversified economy spanning across agriculture, lumber, naval stores, manufacturing industries, and shipping (Watson, 1987). New Bern’s trade routes extended to eastern Atlantic ports including Philadelphia, New Orleans, Savannah, Charleston, and the Caribbean islands (Dill, 1946; Watson, 1987). With the rise of industrialization from the early to mid-19th century, many people migrated from the rural countryside to urbanized centers within the U.S. (Curry, 1974; Haines, 2001). The city of New Bern did not see substantial growth during this period, only increasing in population from 4,681 to 5,432 between 1850 and 1860, primarily due to the annexation of the neighboring town of Dryborough. However, the completion of the North Carolina and Atlantic Railroad in 1858 provided greater transportation of people and goods to and from New Bern, linking it to other regions across the state (U.S. Census Bureau, 1901; Watson, 1987). During the post-Civil War period, New Bern continued to grow to a population of 7,843 in 1890 (Watson, 1987). Manufacturing industries including turpentine production and distilleries, tanneries, sawmills, gristmills, and textile plants helped to fuel the city's economy during the 19th century (Watson, 1987). Additionally, fishing and shipbuilding were popular industries in the port district of New Bern (Watson, 1987). The effects of this rapid urbanization and industrialization in New Bern seemed to have resulted in major health risks to the city's inhabitants.

The increased population density and industrial activities in New Bern resulted in its characterization of a city with inadequate sanitation standards and frequent epidemics due to the lack of proper public health practices and insufficient medical knowledge (McMillen, 1990; Stowe, 2004; Watson, 1987). Until the end of the 19th century, the dominant medical paradigm was the Miasma theory, referring to the noxious vapors or "foul air" that emanated from garbage, dead animals, and human waste that were thought to cause sickness and disease (Brunton, 2013; Watson, 1987). Air pollution emitted by manufacturing industries as well the overflow of trash and animal waste in the streets created poor living and working conditions for inhabitants in urban contexts such as London, Philadelphia, and New York City (Brimblecombe, 1978; Brunton, 2013; Haines, 2001; Watson, 1987), and this may have been true as well for New Bern. In the early to mid-19th century, major U.S. cities in the South such as New Orleans showed high crude death rates of approximately 50 deaths per 1,000 individuals related to rampant epidemics of yellow fever, cholera, and malaria (Haines, 2001). Likewise, U.S. counties serving as major water and/or railroad transportation centers had high crude death rates of 20.5 deaths per 1,000 individuals compared to those without such access (15.6 per 1000 individuals) (Haines, 2001). Additionally, in the 18th and most of the 19th century, physicians in the U.S. lacked standardized medical practices and received poor training from medical schools and/or apprenticeships (Brunton, 2013; McMillen, 1990; Stowe, 2004). Individuals also relied on health manuals such as Child's (1837) "The Family Nurse" which provided remedies and treatments to common illnesses as well as advice for adequate infant and child-rearing (Brunton, 2013). New Bern reflected the poor sanitary conditions of populous urban centers in the 19th century which resulted in detrimental health effects to the citizens.

Throughout the 18th and 19th centuries, epidemics of yellow fever, malaria, smallpox, cholera, and tuberculosis ravaged urban areas in the United States including New Bern (Benjamin, 1865, 2012; Brunton, 2013; Censer, 1984; Humphreys, 1992; McMillen, 1990; Watson, 1987, 2013). Respiratory illnesses and malaria were reported as the most frequent causes of deaths in Craven County during the 19th century (Watson, 1987). The marshy environment and hot, humid climate of eastern North Carolina created ideal breeding grounds for mosquitos and other pests to spread yellow fever and malaria, commonly referred to as "fever and ague" (Benjamin, 1865, 2012; New Bern Historical Society, n.d.; O'Connell, 1891; Watson, 1987). Historical documents reported urban residents should avoid the "night air" and "miasmatic odors" emitted from decaying vegetation and slaughterhouses which could transmit these diseases ("Sanitary", 1862; "The Sickness in New Berne", 1864). Port warehouses containing pools of stagnant water served as suitable breeding grounds for mosquitos (Benjamin, 1865, 2012; Spaight, 1793; Watson, 1987). Historical accounts of the Yellow Fever Epidemic of 1864 described the city as “poor plague-smitten New Bern” and documented a total of 1,300 deaths, leaving the city “closed and desolated” (Benjamin, 1865, 2012; New Bern Historical Society, n.d.). Even with the use of quarantine protocols, members of shipping vessels arriving from major cities sometimes transmitted infectious diseases to the city’s inhabitants (Watson, 1987). The local government did not implement public health infrastructure until the late 19th century with the construction of water and sewage systems and enactment of sanitation laws enforcing trash and waste collections (Watson, 1987). Even with health regulations to improve sanitary conditions of the city, epidemics and illnesses persisted throughout the late 19th century (Watson, 1987).

The rural, country landscape initially seems to have offered an escape from the detrimental effects of 19th century urban living. The cool, open air of the countryside was believed to be healthier than dense, polluted cities (Brunton, 2013; Page, 1851). New Bernians would escape to the countryside and local plantations during the summer season to avoid the “sickly season” when diseases and fevers were the most rampant (Watson, 1987). Although the countryside appeared to have healthier living standards, historical accounts of planter families report high risks of infectious disease related to the marshy environment of the region (Censer, 1984; McMillen, 1990). Fevers, dysentery, hookworm, and malaria were endemic to the region even among the privileged planter families. Plantations were described as “disease reservoirs” because of their warm environment and dense, clustered populations of enslaved peoples, especially in their poor living quarters (McGuire & Coelho, 2020; McMillen, 1990). Hookworm infections were more common in the rural South because of the transmission from the soil through the skin of those without shoes (McGuire & Coelho, 2020). The low-lying, humid environment was conducive for mosquitos with one North Carolina planter wife, Margaret Mordecai Devereux describing the southern coastland as the "land of swamps and ague" (McMillen, 1990). Planter families would leave their "miasmatic plantations" to stay near the coasts, mineral springs or in the mountainous regions that provided more fresh, open air (Brunton, 2013; Censer, 1984; McMillen, 1990). Planter families also had access to physicians and relied on similar treatments and remedies from health manuals as those in urban areas (Foscue, 1853; Stowe, 2004). This evidence demonstrates the health risks of rural, plantation settings which plagued even elite families in the southeastern U.S. during the 18th and 19th centuries.

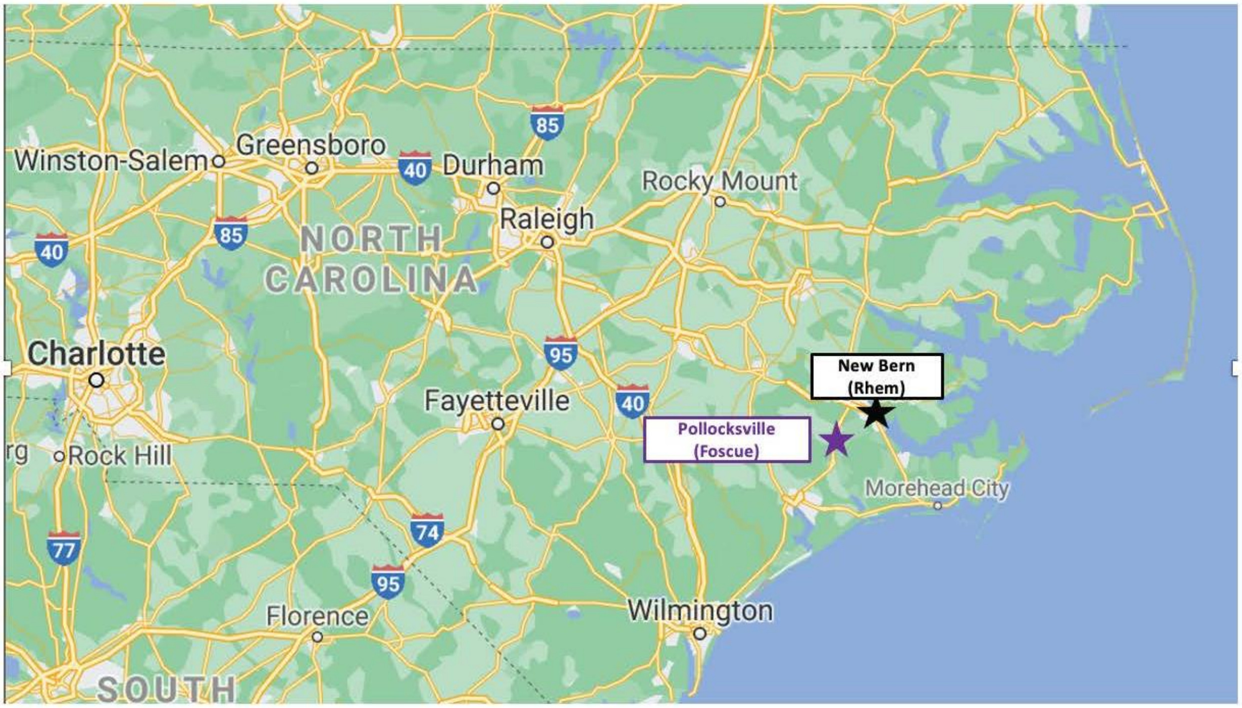

Figure 2.1. Map of North Carolina noting the locations of the urban Rhems (New Bern) and the rural Foscues (near Pollocksville) (Google Maps, 2022).

Urban sample: Rhem family

The Rhem family would have been considered a high-status family in 19th century eastern North Carolina (Figure 2.1). The foundation of their wealth starts with Amos Rhem (1789-1853) who owned a plantation in the neighboring Lenoir County. He married Theresa Lane (1794-1853) in 1810, and the couple had seven children: John (1816-1899), Jacob (1822-1853), Joseph (~1825-1901), Elizabeth (~1826-?), Hannah (~1828-?), Priscilla (1830-1859), and Susan (1834-1897) (U.S. Census Bureau, 1860). Joseph Rhem, Sr. was a prominent figure in New Bern who ventured into various industrial and agricultural endeavors, expanding and diversifying the family's income. Rhem, Sr. controlled a turpentine distillery in Florida and a steam sawmill and mercantile business in New Bern before focusing on his truck farming business ("Copartnership Notice", 1855; "Death of Joseph L. Rhem", 1901; National Park Service [NRHP], 1969). He also served as a delegate of the 2nd Electoral Districts of the State and as a committee member of the New Bern Agricultural Society ("Agricultural Society", 1859; "District Convention", 1856;). Throughout his lifetime, the patriarch solidified the family's status and wealth in the city. According to the *Joseph L Rhem Family Bible, 1860/2020,* Joseph Rhem married his first wife, Ann Kilpatrick (~1831-1853) in 1847 that resulted in three children before her death: Susan Viola Rhem (1848-1928), Martha Ann Rhem (1851-1905), and Amos Rhem (1852-1853). Joseph Rhem then married Sarah Catherine Tucker (1835-1880) in 1855 and they had eleven children: Joseph L. Rhem, Jr. (1857-1871), Sarah C. (1859-1880?), Kate Eula (1859-1943), Lula Newbernia (1862-1867), John (1865-1872), Caroline (1867-1954), Joseph Franklin (1871-1924), Bertha (1876-1877), Mary Bertha (1860-1870?), Frank Hoke (1863-1870?), and Hugh Dudley (1872-1873). Figure 2.2 displays the genealogical relationships of the Rhem descendants who are believed to be in the vault.

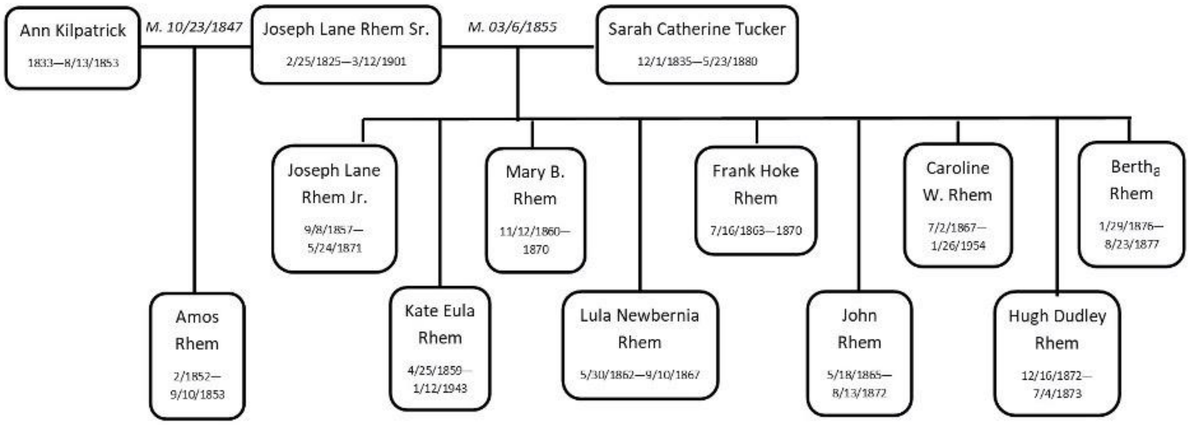

Figure 2.2. Rhem family tree of members purported to be in the burial vault based on genealogical records. Not all individuals in the vault are listed in the family tree (Stewart, 2022).

The Rhem burial vault is located in Cedar Grove Cemetery in New Bern, NC which has served as the predominant cemetery for all members of the city since 1800. However, during the early 1900s, the city required the burials of "freed" and enslaved African American populations to be moved to Greenwood Cemetery to enforce segregation of the cemeteries (NRHP, 1972; New Bern Historical Society, 2021). Cedar Grove Cemetery was originally in a quadrangle layout between the streets of Queen, George, Howard, Metcalf and Cypress and was later expanded in 1853 north across George St between the streets of Main, Cedar, and Bern (NRHP, 1972). The original layout of the cemetery is enclosed by a coquina wall and has a notable triple-pillar arch at the entrance facing Queen St. Notable residents of New Bern are buried here including William Gaston, a 19th century state congressman and Mary Bayard Clark, a 19th century poet and writer (NRHP, 1972). The Rhem burial vault is one of several family vaults in the cemetery in addition to a tall barreled-vault of the Custis family and high-paneled brick-lined vaults of the Battle and Bryan family plots (NRHP, 1972). The construction of a family burial vault and its location in a cemetery among other affluent figures highlights the wealth and high status of the Rhem family.

The construction of the Rhem vault occurred in the early 1850s around the time Rhem, Sr. purchased the "Rhem-Waldrop House" in 1855 that is still standing at the southwest corner of Broad and George St. (NRHP, 1972). The exterior design of the Rhem vault parallels the stucco and red-brick exterior of the Rhem-Waldrop house (NRHP, 1972). Based on historical and genealogical information provided by the descendants, the Rhem burial vault was actively used over three generations (*Joseph L Rhem Family Bible, 1860/2020*). According to genealogical information, the following individuals were expected to be present in the vault along with Joseph Rhem, Sr.: Joseph, Sr.'s first wife Ann Kilpatrick and their son Amos Rhem as well as his second wife Sarah Catherine Tucker and their children Joseph Rhem Jr. (1857-1871), Kate Eula Rhem (1859-1943), Mary B. Rhem (1860-1870?), Lula Newbernia Rhem (1862-1867), Frank Hoke Rhem (1863-1870?), John Rhem (1865-1872), Caroline W. Rhem (1867-1954), Hugh Dudley Rhem (1872-1873), and Bertha Rhem (1876-1877), along with Sarah Catherine Rhem (1835-1880) and Elizabeth Ann Pelletier Fisher (1821-1863). According to the family bible, Fisher was a friend of the Rhem family who passed away in 1863 when New Bern was invaded during the Civil War. The first burials date to the 1850s with the presumed interment of his first wife, Ann Kilpatrick and child, Amos Rhem in 1853, while the most recent burial is Harlowe Waldrop (1893-1972), the husband of Eula Cole and son-in-law of Carrie Rhem Cole, in the 1970s. Stewart (2022) expands upon the estimated identifications and relation of the interred individuals in the vault.

Figure 2.3. Front aspect of Rhem burial vault in Cedar Grove Cemetery in New Bern, North Carolina. Photo by Dr. Megan Perry

Rural sample: Foscue family

During the 18th-19th centuries, the Foscues were an elite planter family in rural eastern North Carolina (Perry et al., in press) (Figure 2.1). The family patriarch, Simon Foscue, Sr. (1734-1814) established himself in North Carolina in the late 18th century and early 19th century. After relocating from Virginia, he obtained land north of the Trent River in Jones County in 1782, which he further expanded to 1,750 acres by 1809 (Foscue, 1753-1801; Harriett, 1987). The Foscue family were leading producers of cash crops such as tobacco and cotton as well as naval stores like turpentine and tar in North Carolina, therefore establishing their affluent status in the rural region. Simon, Sr. had three marriages: Sarah Sanderson Brockett (1739-1778) in 1759, Nancy Mitchell (1749-1795) in 1779 and Elizabeth Ann Stephenson (1775-1840?) in 1800. Most of the land was bequeathed to the firstborn sons of Sarah (Frederick, 1765-1834) and Nancy (Simon Jr., 1780-1830). Simon Foscue, Jr. married Christiana “Kitty” Rhem, the paternal aunt of Joseph Rhem Sr., in 1801.

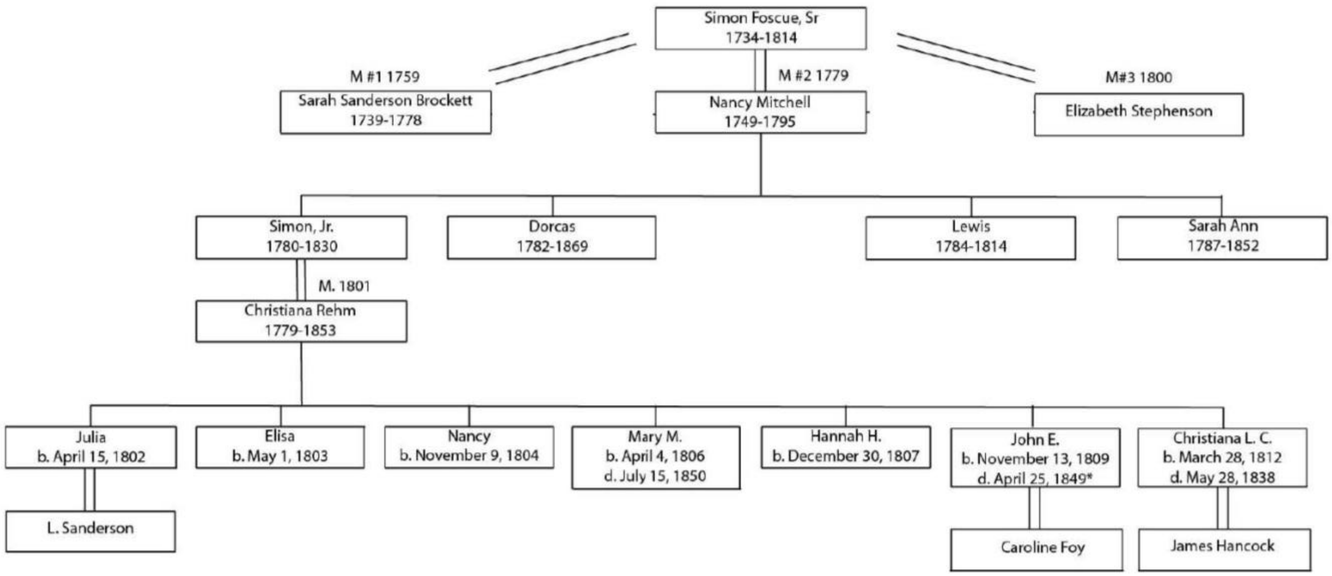

Figure 2.4. Foscue family tree. Not all members listed in this family tree were present in the vault (Seeman, 2011).

Sometime in the 1820s, Simon Foscue Jr. expanded his landholdings to 2,700 acres near Pollocksville, NC in which eight acres were allocated to construction of the two-story brick plantation house and the adjacent Foscue burial vault. The vault is located less than one mile behind the plantation house and was exclusively for the burial of family members (Figure 2.4). According to historical documents, three individuals were interred in the vault in the following order from earliest to latest: Simon Foscue, Sr., Simon Foscue, Jr., and Kitty Rhem Foscue. Staff and students of ECU excavated the vault in 2010, discovering that the vault was partially above ground and covered with a brick gabled roof (Seeman, 2011). The interior of the vault was filled with a dense layer of the bricks from the collapsed roof covered by soil to the ground level and topped with a layer of bricks to consolidate the structure. The intact portion of the vault below-ground measured 8.8 ft. E-W and 14 ft. N-S and was 4.5 ft. in height. The entry way was located at the northern end and six brick pillars were present in each corner and midway on the eastern and western walls. The pillars did not reach the top of the vault (those on the eastern side measured 1 meter high and 1.5 meters on the western side), indicating their potential use for structural support of the roof acting as springers or more likely serving as supports for coffin shelving. Fragments of plaster were also present in the vault, suggesting the interior was lined with this material and evidence of disturbances from tree growth was also present in the vault. Commingled skeletal remains of nine individuals were present on or near the vault floor with clear taphonomic changes caused by tree root growth and looting (Seeman, 2011).

Despite the commingling, many of the Foscue elements were individuated and linked to possible identities derived from family histories and genealogical data (Perry et al., in press; Seeman, 2011). The nine individuals recovered from the vault include four adults (four females and one male) ranging in age from 25-60+ years old and three subadults including one 3-year-old and three neonates (31-36 gestational weeks of age). The subadults most likely are Simon, Jr.'s grandchildren who died between 1830-1849 (Perry et al., in press). Two of the neonates of similar ages (31- 32 gestational weeks of age) are possibly the twins of Simon, Jr.'s daughter, Christiana (1812-1838) who died at the age of 26 during childbirth (Foscue, 1895). One of the three neonates could also be the infant of Julia (1802-1877), the eldest daughter of Simon, Jr. or the infant of Hannah (1807-1843), the youngest daughter of Simon, Jr (Foscue, 185). Hannah is also the possible mother of the 3-year-old (+/-12 months) subadult who is ascribed to the individual of the same name (Foscue, 1895). Skeletal analysis of age estimation and pathologies is discussed in later sections. A burial vault dedicated to members of the family suggests continued presence of wealth throughout the families' generations.

Figure 2.5. Interior of the Foscue vault showing commingled remains and tree root intrusion during excavation (Seeman, 2011).

Bioarchaeological investigation of morbidity and mortality in subadults

Bioarchaeology frames the discipline of human biology within cultural contexts to understand the health and lifestyles of past populations. Bone is a dynamic, adaptive structure composed of specialized cells, osteoblasts, osteoclasts, and osteocytes which constantly produce, maintain, and remodel bone tissue in response to physiological and biomechanical forces (Brickley, Ives, & Mays, 2020a; Halcrow & Tayles, 2011; Larsen & Walker, 2010). These specialized cells may deposit and/or resorb bone in response to “stressors” such as pathogens, trauma, and nutritional deficiencies, manifesting in a range of skeletal and dental pathologies (Brickley et al., 2020a; Goodman, Thomas, Swedlund, & Armelagos, 1988; Goodman & Armelagos, 1989). “Stress” is described as any physiological disruption resulting from environmental, nutritional, or other pressures (Goodman et al., 1988; Goodman, Martin, & Armelagos, 1984; Huss-Ashmore, Goodman, & Armelagos, 1982; Reitsema & McIlvaine, 2014). Diseases such as tuberculosis and syphilis produce pathognomic lesions and thus can be identified in bone, while many other stressors result in a range of generalized, non-specific indicators such as porosity, abnormal new bone formation, stunted long bone growth and dental defects. Additionally, certain conditions may only affect soft tissue or are too acute to result in skeletal lesions (Brickley et al., 2020a; Goodman et al., 1988; Goodman & Armelagos, 1989). There is an extensive history of bioarchaeological studies analyzing skeletal stressors to measure health status and understand lifestyles of adults and subadults in past populations (Buikstra & Beck, 2017; Larsen & Walker, 2010).

Skeletal remains of subadults provides extensive information about their biological and cultural life related to their birth, growth and development, diet, age-at-death, and risk of disease and trauma due to their economic and social status at different life stages (DeWitte &

Stojaknowski, 2015; Goodman & Armelagos, 1989; Halcrow & Tayles, 2011; Lewis, 2007). Subadults are entirely dependent on the care of others and represent the most vulnerable members of a society. Subadult health and survival are demographically variable and sensitive to environmental and social changes in a population. Patterns of infant and child mortality have significant impact on the overall mortality rates of populations and when combined with patterns of morbidity, serve as measures of population fitness and evolutionary adaptedness (Goodman & Armelagos, 1989; Halcrow & Tayles, 2011; Lewis, 2007). There is extensive bioarchaeological literature focused on the morbidity and mortality of subadults that aims not only to understand the health status of populations, but also recent integrated frameworks with life course theory that explore intergenerational effects of health and stressors influenced by their sociocultural contexts.

Early bioarchaeological investigations of subadults primarily focused on metric and non-metric methods of age and sex estimation, including Francis Johnston, who examined growth rates of subadults from Indian Knoll in Kentucky (Boucher, 1955; Scammon and Calkins, 1923). Paleopathological research later emerged with studies linking iron-deficiency anemia as the cause of porotic hyperostosis in subadults (El-Najjar, 1977; Lallo, Armelagos, & Mensforth, 1977) and enamel hypoplasias associated with early childhood stress (McHenry, 1968; McHenry & Schulz, 1976; Rose, Condon, & Goodman, 1978). Goodman and Armelagos (1985) noted the significance of subadults less than five years old as the most susceptible individuals of a population to environmental and cultural stressors. In their paleopathological studies, Ortner and other scholars identified clusters of lesions associated with specific diseases and nutritional deficiencies such as vitamin C (scurvy) and vitamin D (rickets) in subadults (Ortner and Ericksen, 1997; Ortner and Mays, 1998; Ortner, Kimmerle, & Diez, 1999; Ortner, 2003).

Throughout the timeline of bioarchaeological research, analysis of subadults has provided valuable insight in understanding the biological and cultural interactions that impact the health and lifestyles of past populations.

Recent bioarchaeological literature has explored the intricate relationship of the mother-infant nexus and the significance of the first 1000 days of life on fetal/infant growth and development as well as the influence of endogenous and exogenous factors on morbidity and mortality (Beaumont, Montgomery, Buckberry, & Jay, 2015; Brickley, Kahlon, & D'Ortenzio, 2020b; Halcrow, 2020; Hodson & Gowland, 2020; Gowland, 2015, 2018; Gowland & Halcrow, 2020; McDade, 2003; Miller, 2020; Schwarzenberg et al., 2018; Temple, 2020). The first 1000 days of life, starting from conception to generally two years of age, have been identified as a crucial period for developmental plasticity and increased vulnerability to early life adversity (Barker et al., 2002; Barker, 2012; Schwarzenberg et al., 2018). Poor environmental conditions during the prenatal and postnatal periods can shift the trajectory of growth and development in order to support significant development of key organs, with the brain at the top of the hierarchy. Sufficient nutrition of key sources including protein, zinc, and vitamins A, D, and B-6 and B-12 is necessary for proper somatic formation and maintenance (Schwarzenberg et al., 2018). Related to this early window of development, the "biometric model" developed by Bourgeois-Pichat (1951) states that endogenous mortality occurs within the first month of life while exogenous mortality is proportional to the number of days, after the first month, the infant survives (Lewis, 2007). Perinatal (24 weeks of gestational age to 7 post-natal days) mortality and neonatal (7 post-natal days to 27 post-natal days) mortality are related to endogenous factors of maternal and infant health including congenital abnormalities, childbirth complications, prematurity, and low birth weight (Lewis, 2007; Scott & Duncan, 1999). Post-neonatal (28 post-natal days-1 year) mortality is associated with exogenous factors of their environment such as infectious disease, malnutrition, poisonings, and trauma (Lewis & Gowland, 2007; Scott & Duncan, 1999). Proceeding after 1 year of age, children are still susceptible to exogenous risks especially in association with the weaning period increasing their vulnerability to infectious disease and malnutrition (Goodman & Armelagos, 1989; Katzenburg, Herring, & Saunders, 1996; Lewis, 2007). The ability of a population to provide the appropriate biocultural care for a child's survival after birth reflects their general successive adaptability.

Even past the 1-month mark of endogenous mortality, maternal immunity can influence the health and development of the infant continuing into childhood and adulthood, illustrating the importance of the life course perspective in which an individual's health is intertwined throughout past and future generations (Gowland, 2015). Growing research supports that infants are not discrete, bounded entities, but rather are integrated with the physiological and sociocultural experiences and health of their mother even in utero (Barker, 2012; Gowland, 2015; Gowland & Halcrow, 2020; Schwarzenberg et al., 2018). A mother's life experiences during childhood including exposure to physical and psychological stressors have shown to impact the health and development of their offspring, illustrating the concept of "linked lives" across generations (Gowland, 2015; Jones et al., 2019; Sletner et al., 2014). Poor maternal health linked to nutritional deficiencies, infectious disease, or other conditions can compromise the intrauterine environment, hindering proper fetal development (Barker, 2012; Gowland, 2015; Schwarzenberg et al., 2018).

Bioarchaeological studies have inferred maternal health status based on evidence of metabolic disease and growth disruption from fetal and infant remains in the first 1000 days of life (Brickley et al., 2020b; Hodson & Gowland, 2020; Perry & Edwards, 2021; Snoddy, Halcrow, Buckley, Standen, & Arriaza, 2017). In a study of fetal, perinatal, and infant remains from a low status post-Medieval London (16th-19th century) population, Hodson & Gowland (2020) note the prevalence of metabolic disease and severe growth disruption, suggesting the influence of poor intrauterine conditions due to maternal deficiencies. The authors note that the cultural and environmental effects of low socioeconomic status and squalid urban conditions inhibited early life growth and health outcomes. Snoddy et al. (2017) details skeletal manifestations of scurvy in perinates and both members of a purported mother-infant burial in a northern Chile site (3600-3200 BP) as a possible result of resource scarcity related to climactic transitions, also highlighting the interwoven nature of nutritional status and health in the mother-infant nexus. Thus, skeletal evidence of physiological stressors including metabolic disease in infant remains can suggest maternal health status and the influence of endogenous factors in mortality and morbidity as well as shed light on the intergenerational dynamics of health and development. Exogenous and endogenous factors can reveal differential morbidity and mortality patterns in urban and rural regions in the 18th-19th century southeastern U.S.

One example of exogenous factors impacting health outcomes are child rearing practices in the 18th and 19th century U.S. which proved to be detrimental to childhood health. For instance, mothers were encouraged to breastfeed their infants unless they abstained or were ill in which they relied on wet nurses or alternative food sources (Censer, 1984; Child, 1837; McMillen, 1990). Physicians advised breastfeeding mothers to consume meat, fowl, and fish but avoid foods like vegetables that were sharp, sour, salty, bitter which could upset the stomach of the infant (Child, 1837; Schmidt, 1976). Physicians also did not recommend for children to intake high amounts of meat, vegetables, and fruit which were believed to induce stomach issues (Child, 1837; Schmidt, 1976). As a last resort, mothers fed bland foods to the infant including “pap” and “panada” to avoid gastrointestinal issues (Child, 1837; McMillen, 1990; Schmidt, 1976). Pap was a combination of bread or flour boiled in water with or without the addition of milk, and panada was a mixture of cereals, flours or breads with butter or milk boiled in broth (McMillen, 1990; Schmidt, 1976). Weaning ages varied although infants could start as early as 3 months to 12 months of age with the introduction of alternative foods before they were fully weaned around 6 months to 2 years of age (Censer, 1984; Child, 1837; Fildes, 1995; McMillen, 1990; Schmidt, 1976). Additionally, bacterial contamination of feeding bottles due to poor sanitation was a common issue, further threatening the health of infants (McMillen, 1990; Schmidt, 1976). Infants and children during this period were at risk of malnutrition and infection due to nutritionally poor diets and contamination of their food sources.

These risks reflect the high infant and child mortality rates of the 18th and 19th century and risk of morbidity related to epidemics, insufficient diets, and inadequate rearing practices. The poor diets of mostly bread, sugar, and water led to chronic malnourishment including metabolic diseases such as vitamin C and vitamin D deficiencies that facilitated these morbidity risks. Treatment for scurvy in adults via consumption of fruits was not applied to infants and children until the later 19th century. Rickets and scurvy were common diseases of the wealthy as they would wean their infants on nutritionally inefficient formulas (Fildes, 1986; Schmidt, 1976; Zhang et al., 2016). During the Industrial Era in Europe, children living in urban areas also developed rickets due to air pollution blocking sunlight necessary for vitamin D synthesis (Lewis, 2002; Newman, Gowland, & Caffell, 2019). These environmental conditions and cultural practices in infant and child care-taking affected the health and development of infants and children during the 18th and 19th centuries.

Evidence of poor health outcomes in infants due to the environment, diet, and weaning practices can be assessed by the pattern of skeletal lesions and age-at-death mortality within a sample. For example, it is possible to identify skeletal evidence of insufficient levels of vitamin C and vitamin D resulting from poor maternal nutrition or a limited nutritional diet due to weaning (Brickley et al., 2020a). Malnutrition and infectious or parasitic disease have a synergistic relationship which can also result in skeletal and dental non-specific indicators of stress (Keita, 2003; Roberts & Brickley, 2018). Subadults are sensitive to these physiological disruptors due to their rapid bodily and skeletal formation. Vitamin C is necessary for the formation of type 1 collagen which provides structure to connective tissues including bone, ligaments, and blood vessels (Brickley et al., 2020a; Fain, 2005). Collagen is formed through the hydroxylation reactions of enzymes proline and lysine, which bond amino acids to form a polypeptide chain for collagen. Unlike most animals, humans acquire vitamin C exclusively through their diet, with high levels present in fruits, vegetables, and human breastmilk (depending on the nutritional status of the mother), while meat, fish, and milk have smaller amounts (Brickley et al., 2020a; Fain, 2005; German Nutrition Society, 2015). Because vitamin C is water soluble and is not stored in the body, frequent consumption of these foods is necessary to maintain adequate vitamin C levels. Cooking and storage processes can affect the levels of vitamin C in food sources as oxidation and use of heat breaks down the vitamin C contents (Brickley et al., 2020a; Fain, 2005).

The development of collagen in vitamin C deficiency results in several musculoskeletal changes, including weakened vessel walls and depressed osteoblastic activity which reduces or arrests the deposition of the collagenous bone matrix, thus failing the formation of osteoid (Brickley et al., 2020a; Fain, 2005). Normal bone resorption will continue, thinning the cortical and trabecular bone and widening the gaps in the trabeculae (Brickley & Ives, 2006; Brickley et al., 2020a). This demineralized bone will lead to metaphyseal fractures in long bone and "Pelkan spurs", which are healed lesions on the lateral edges of bone (Brickley et al., 2020a). Weakened blood vessels lead to hemorrhaging, resulting in the formation of cortical porosity (<1 mm in diameter) and/or periosteal new bone formation (Brickley et al., 2020a). These lesions will be evident in subadults because of increased risk of hemorrhaging and less secure attachment of the periosteum to the bone due to rapid bone formation and development of tissues (Brickley & Ives, 2006; Brickley et al., 2020a; Ortner & Erickson, 1997). Common sites of these lesions include the greater wing of the sphenoid, orbital roofs of the frontal bone, alveolar processes of the mandible and maxilla, endo and ectocranial surface of the cranial vault, supra- and infra-spinous fossae of the scapula, metaphyseal region of the long bones, and ilia (Brickley & Ives, 2006; Brickley et al., 2020a; Geber & Murphy, 2012; Klaus, 2014; Ortner & Erickson, 1997; Ortner et al., 1999; Snoddy et al., 2018). Bilateral porosity on the greater wing of the sphenoid is suggested as a strong pathognomic feature of scurvy (Ortner & Erickson, 1997; Ortner et al., 1999).

Vitamin D deficiency can result in the formation of rickets in subadults. Vitamin D is a fat-soluble vitamin and has several roles in the body including metabolic maintenance of calcium and phosphorous to enable proper bone mineralization (Brickley et al., 2020a; Holick, 2005; Lewis, 2007; Pearce & Cheetham, 2010; Pettifor, 2008; Roberts and Brickley, 2018; Snoddy, Buckley, & Halcrow, 2016). Vitamin D is mostly obtained through skin exposure to sunlight (UVB) and in smaller amounts through diet including foods such as milk, fish, and eggs. Human breastmilk has low quantities of vitamin D especially in mothers who lack regular sun exposure (Ballard & Marrow, 2013). Vitamin D is synthesized into the body through hydroxylation in the liver, converting vitamin D into 25-hydroxyvitamin D [25(OH)D], and in the kidneys to form

1,25-dihydroxyvitamin D [1,25(OH)2D. Serum levels less than 27 nmol/L of the main circulating form of vitamin D, 25-hydroxyvitamin D [25(OH)D] indicate severe vitamin D deficiency (Holick, 2005; Pearce & Cheetham, 2010; Pettifor, 2008; Roberts and Brickley, 2018). Vitamin D stimulates osteoblasts and cartilage cells also known as chondrocytes to induce cell differentiation, osteoid synthesis, and mineralization (Brickley et al., 2020a; Holick, 2005). Vitamin D deficiencies disrupt the deposition process of calcium and phosphate, leading to defective bone mineralization and thus, creating weakened bone structure that results in shape abnormalities and abnormal bone loss visible in rickets (Brickley et al., 2020a; Holick, 2005). Genetic conditions can also manifest rickets such as autosomal-dominant hypophosphatemic rickets which involves the overproduction of fibroblast growth factor-23 (FGF23), a 32 kDa glycoprotein, produced by osteoblasts and osteocytes, that suppresses vitamin D in the kidneys (Brickley et al., 2020a; Erben, 2018; Sahay & Sahay, 2013). Other causes include gastrointestinal diseases such as inflammatory bowel disease (IBD) which reduces [25(OH)D3 levels during inflammatory episodes and Crohn's disease resulting in reduced intestinal area for absorption of vitamin D (Han, Margulies, Kurian, & Elliott, 2016; Raman, Milestone, Walters, Hart, & Ghosh, 2011). Subadults during the 18th and 19th century may have also experienced these non-nutritional forms of rickets although these cases are rare.

Skeletal manifestation of rickets is most evident in subadults, particularly those aged from 3 to 18 months in modern populations, due to rapid turnover of bone during infancy and childhood (Brickley et al., 2020a; Ives, 2018; Mays & Brickley, 2018; Ortner & Mays, 1998; Pettifor, 2008). Metaphyses of long bones and sternal ends of ribs present signs of porosity, flaring, and fraying due to improper endochondral ossification of the cartilage, weakening the bone tissue (Brickley et al., 2020a; Ortner & Mays, 1998). This demineralization on the long bones and ribs is described as slit/strut anatomy due to “slits” or gaps in the bone tissue, indicating a lack of osteoid deposition (Brickley et al., 2020a; Ortner & Mays, 1998). Biomechanical loading of the demineralized bone can lead to abnormal bowing and angulation of the long bones which are visible in both active and healed rickets. The neck and head of the femur can be angled inferiorly known as “coxa vara” due to compression at the hip from walking. Additionally, porosity is localized on the external surface of the cranial vault and orbital roof of the frontal bone (Brickley et al., 2020a). Reintroduction of vitamin D into the body activates osteoid mineralization, resulting in new bone formation on the cranial vault and long bones (Brickley et al., 2020a; Ortner & Mays, 1998).

Other non-specific indicators of stress linked to nutritional deficiencies as well as infection and trauma include dental defects such as linear enamel hypoplasias (LEH) (Goodman & Armelagos, 1985; Goodman & Rose, 1990; Lewis, 2007; Rose et al., 1985). LEH are noticeable grooves in the enamel that represent periods of physiological disruption during enamel formation of tooth crown development (Goodman & Armelagos, 1985; Goodman & Rose, 1990). These periods of stress can be the result of trauma including the process of birth, low birth weight or premature birth (Nelson et al., 2013; Pimlott, Howley, Nikiforuk, & Fitzhardinge, 1985), pre- and postnatal malnutrition (Goodman & Rose, 1990; Masterson et al., 2017), weaning (Blakely & Armelagos, 1985; Katzenburg et al., 1996), diseases and infections including congenital syphilis (Nissanka-Jayasuriya, Odell, & Phillips, 2016), and tuberculosis (Knick, 1982). LEH on the deciduous dentition reflects maternal stress during the last 2 trimesters of pregnancy, and those present on the permanent dentition can develop anytime between birth to 6 years of age (Goodman & Armelagos, 1989). Anterior teeth including the incisors and canines are more susceptible to LEH formation due to their earlier initiation of enamel development and longer period of crown completion (Goodman & Armelagos, 1985; Reid & Guatelli-Steinberg, 2017). Distance of the LEH from the cemento-enamel junction (CEJ) allows for estimating the LEH age of occurrence using exponential regression equations (Henriquez & Oxenham, 2018). The prevalence of LEHs and their age estimates can help to understand different environmental and cultural stressors at different periods of childhood in the urban Rhem and rural Foscue populations.

Another dental indicator of diet and disease susceptibility is carious lesions. These defects often result from carbohydrate-rich diets in which oral microorganisms in dental plaque metabolize sugar resulting in production of organic acids and demineralization of the enamel, dentin, and cementum (Hillson, 2005; Pitts et al., 2017). Dental caries was prevalent during the industrial-era especially in the latter half of the 19th century in the U.S. with increased dietary consumption of refined flour and sugars in addition to limited knowledge of dental hygiene (Mant & Roberts, 2015; Ross, 1993; Saunders, De Vito, & Katzenburg, 1997). Isotopic evidence of North Carolina populations from this period reveals a carbohydrate-rich diet consisting of C_3 and C_4 plants including high amounts of corn, rice, sugar, wheat, potatoes, and peas, as well as a reliance on marine and terrestrial sources of meat, indicating the potential risk for caries in subadults (Pitts et al., 2017; Taylor, 2020). Increased risk of dental caries is also linked with chronic periods of malnutrition as anti-cariogenic components of salivary production diminish with lowered nutritional status (Vieira et al., 2020) as well as during pregnancy (Mital et al., 2013; Silk, Douglass, Douglass, & Silk, 2008). Pregnant mothers are more likely to develop caries due to higher acidity of the oral cavity and increased sugar consumption in their diet, and likewise, children of mothers with extensive caries are also at increased risk of caries (Silk et al., 2008). Other risk factors for caries include genetic variation of oral bacteria, enamel formation and microstructure, and salivary production (Larsen, 2018; Lukacs, 2011). Caries was a common health issue in subadults during the 18th-19th centuries due to excessive consumption of sweets and use of high carbohydrate weaning foods such as pap and panada containing refined flour and cornmeal (Bruwelheide et al., 2020; Owsley, Bruwelheide, Barca, Reidy, & Fleskes, 2018). Caries risk is helpful in understanding the morbidity and mortality risks of subadults during this period.

Porotic hyperostosis (PH) and cribra orbitalia (CO), additional skeletal indicators of health, appear as areas of porosity localized on the cranial vault and the orbital roofs of the frontal bone, respectively. These pathologies form from over-proliferation of red blood cells generated by the red bone marrow which leads to expansion of the cranial diploë, thinning the cranial vault and orbital roofs (Walker, Bathurst, Richman, Gierdrum, & Andrushko, 2009). Blood cell production occurs in red (hematopoetic) bone marrow and at younger ages, the focal point of hematopoetic marrow is in the diploë of the cranium (Brickley, 2018; Brickley et al., 2020a). Evidence of PH and CO are significant indicators of malnutrition and related infections especially in subadults. Several different etiologies are attributed to these lesions including anemias related to iron-deficiencies, vitamin B-12 deficiencies, parasitic infections, and genetic conditions including thalassemia and sickle-cell anemia (Brickley, 2018; Brickley et al., 2020a; McIlvaine, 2015; Rivera & Lahr, 2017; Stuart-MacAdam, 1985, 1987; Walker et al., 2009).

Interpretation of lesion frequencies, particularly extrapolating them to the population level, needs to consider underlying factors regarding the composition of the sample, often referred to as the “Osteological Paradox” (Wood et al., 1992; DeWitte & Stojaknowski, 2015). Subadults in a skeletal assemblage represent the “non-survivors” of the population and thus do not directly reflect the health status of an entire living population (DeWitte & Stojaknowski, 2015). Underlying factors invisible to the researcher can impact whether or not someone ends up in this mortality sample at a particular age, often referred to as "selective mortality." In addition, population level data masks differential risks of developing a skeletal lesion within a community due to access to resources, genetic variation affecting host response to infection, and microenvironments, referred to as "hidden heterogeneity". These factors may overshadow differences in health within and between populations if not considering the biocultural context (Wood et al., 1992). Projecting the health status of the Rhem and Foscue individuals to the general health of urban and rural populations in this region and time period should be treated with caution with serious consideration of their socioeconomic status and hidden risk factors.

Bioarchaeological studies of urban and rural environments

Data from other bioarchaeological comparisons of rural and urban environments can build expectations for analysis of the Rhem and Foscue burial vaults. There are limited bioarchaeological investigations comparing urban and rural populations in the United States. These studies have mainly focused on the health of urban and rural enslaved and free African American communities in the late 19th century southern U.S. (Blakely & Beck, 1982; Davidson et al., 2002; Franklin & Wilson, 2020). However, there is more extensive urban-rural bioarchaeological research of countries in Industrial-era Europe during the 18th and 19th centuries that parallels the contexts of the southeastern United States. Historical literature of this period notes similar descriptions of the rural countryside having greater health outcomes related to the fresh air and open landscapes while those living in industrialized, dense urban centers faced greater risks of infection and disease due to the unsanitary, crowded conditions (Crane-Kramer & Buckberry, 2020; Williams & Galley, 1995).

Several bioarchaeological studies indicate the detrimental health effects of urban living during the era of European industrialization (Boyd, 2020; Casna & Schrader, 2022; Crane-Kramer & Buckberry, 2020; DeWitte, 2014; Gowland, Caffell, Newman, Levine, & Holst, 2018; Lewis, Roberts, & Manchester, 1995; Lewis, 2002; Lewis & Gowland, 2007; Mays, Brickley, & Ives, 2008; Mays, Ives, & Brickley, 2009; Newman & Gowland, 2017; Newman et al., 2019; Newman & Hodson, 2021; Palubeckaitė, Jankauskas, & Boldsen, 2002; Reedy, 2020; Yaussy, 2019). Investigations of industrial England report high prevalence of metabolic diseases including scurvy and rickets and infectious diseases exacerbated by urban environmental contexts and their overcrowding (facilitating transmission of pathogens), air pollution, unsanitary working and living conditions, and food and water contamination (Gowland et al., 2018; Lewis et al., 1995; Lewis, 2002; Lewis & Gowland, 2007; Mays et al., 2008; Mays et al., 2009; Newman & Hodson, 2021; Reedy, 2020; Yaussy, 2019). Demographic reports from industrial England note that urban areas exhibited higher infant mortality rates of epidemic and respiratory diseases due to the negative health risks associated with industrialization compared to higher mortality rates attributed to old age in rural areas (Crane-Kramer and Buckberry, 2020). These studies indicate the significant impact of environmental factors associated with industrialization including high population density, pollution, and infectious disease on health outcomes of urban groups. However, scholars have also found differential morbidity and mortality patterns of urban and rural settings related to the dynamics of environmental factors and sociocultural practices impacting health outcomes (Gamble, 2020; Gowland et al., 2018; Mays et al., 2008; Redfern, DeWitte, Pearce, Hamlin, & Dinwiddy, 2015; Veselka, Hoogland, & Waters-Rist, 2015; Walter & DeWitte, 2017).

On the other hand, several urban-rural bioarchaeological studies of industrialized Europe reveal mixed morbidity and mortality patterns that counter traditional interpretations of a binary health divide (Gowland et al., 2018; Mays et al., 2008; Veselka et al., 2015). A study of industrial-era English subadult (<36 weeks to 20 years old) populations by Gowland et al. (2018) found that both the urban and rural groups exhibited similar prevalence rates of scurvy, rickets, and dental enamel hypoplasias although rural subadults showed higher rates of growth disruption, cribra orbitalia, and respiratory diseases. Greater evidence of growth disruption, cribra orbitalia, and respiratory disease may stem from a higher number of adolescents in the rural population due to the migration of young workers from urban areas seeking labor opportunities at rural industrial sites. These rural sites included textile and flax mills that exposed teen workers to health risks from the arduous labor practices and air pollution resulting in tuberculosis and byssinosis. The comparable stressors exhibited by the urban and rural groups due to the influence of migration and socioeconomic status counters traditional views of salubrious rural environments, supporting evidence of an "urban-rural health continuum" rather than a strict dichotomy (DeWitte & Betsinger, 2021).

Mixed impacts on growth in rural and urban populations were also noted by Mays et al. (2008). The authors discovered no significant differences in endochondral long bone growth between working-class urban and rural subadult populations in 18th-19th century England. The urban population displayed smaller long bone dimensions in the younger individuals (<2 years old) compared to the subadults in the rural population, but more rapid growth in those older than 2 years. These results may suggest that the rural infants were buffered by prolonged breastfeeding and maternal passive immunity while older populations in urban contexts were able to overcome early growth deficiencies with catch-up growth. Additionally, Veselka et al. (2015) note a high frequency of rickets in 19th century Dutch rural subadults aged 2-3 years old associated with poor weaning diets of pap and cow's or goat's milk, excessive swaddling (longer than six months), and restrictive clothing compared to urban English and Dutch populations. Thus, this evidence shows the differential impact of environmental conditions and cultural practices on morbidity and mortality patterns in urban and rural environments during the era of industrialization.

Furthermore, post-neonatal mortality is shown to be higher than neonatal mortality in urban areas due to exogenous factors of poor environmental conditions and weaning practices (Budnick & Liczbińska, 2006; Landers, 1990; Lewis & Gowland, 2007; Ludlow & Hackett, 2019; Saunders et al., 2002; Vögele, 1994; Williams & Galley, 1995). Budnick & Liczbińska (2006) found high post-neonatal mortality rates related to respiratory diseases, dysentery, and diarrhea in the urban, industrialized centers of 19th century Poland based on demographic data. In contrast, rural groups in Poland exhibited higher rates of neonatal mortality related to premature births and low birth weights due to limited medical access and arduous working conditions for women. Additionally, studies have shown higher post-neonatal mortality rates in urban regions related to risks of weaning practices including insufficient food sources and increased risk of infection exacerbated by poor environmental conditions (Lewis, 2002; Lewis & Gowland, 2007; Ludlow & Hackett, 2019). Ludlow & Hackett (2019) note early weaning practices in industrial late 19th and early 20th century Ontario were associated with high post-neonatal mortality due to diarrheal and respiratory diseases from their unsanitary living conditions. Lewis and Gowland (2007) found a greater proportion of post-neonatal deaths in the industrial London group compared to higher neonatal mortality rates of the rural medieval and post-medieval group, noting the urban groups experienced early weaning practices at 7 months of age and poor sanitary livings conditions. On the other hand, Saunders et al. (1995) note a higher proportion of post-neonates (74%) than neonates (26%) in an industrial Belleville, Ontario sample due to poor industrial conditions and poor nutrition impacting young infants. The authors also note an increase in child mortality past the weaning age of 5-7 months suggesting increased susceptibility to exogenous factors including contaminated food and water, infectious disease, and poor nutrition. Therefore, the exogenous risks of weaning practices and poor environmental conditions greatly impacted the health and mortality of infants and children in urban groups while rural areas experienced greater endogenous risks.

Increased social stratification has shown to impact quality of life especially during the era of industrialization resulting in increased health disparities (de la Cova, 2014; DeWitte, Hughes-Morey, Bekvalac, & Karsten, 2016; Yaussy, 2019; Newman & Gowland, 2017; Newman & Hodson, 2021; Reedy 2021; Giuffra et al., 2015; Gowland et al., 2018). In several countries, the privileges of high socioeconomic status including adequate nutrition, sanitary living and working conditions, and access to healthcare services generally serve as a buffer to negative health outcomes (Bosworth, 2018; Cavigelli & Chaudhry, 2012). However, there is mixed bioarchaeological evidence of the relationship between socioeconomic status and quality of life during this era of industrialization (DeWitte et al., 2016; Giuffra et al., 2015; Newman & Gowland, 2017; Reedy, 2021; Saunders et al., 2002). DeWitte et al. (2016) found, as expected, increased mortality and reduced survival of children during industrial-era London, suggesting strong selective mortality for lower socioeconomic status in subadults during industrial-era London. The authors attribute this to weaning practices through the use of dry-feeding such as mixtures of broth, milk, water, and grains lacking the proper nutritional and immunological properties of breastmilk. Additionally, malnutrition increased their susceptibility to the health consequences of unsanitary living conditions, contaminated food and water sources, pollution, and infectious disease. In contrast, high-status groups implemented differential weaning practices which increased morbidity and mortality risks in infants and children (Giuffra et al., 2015; Newman & Gowland, 2017; Reedy, 2021; Saunders et al., 2002). The ability of high-status families to employ artificial weaning sources such as wet nurses, despite cautions against their use by physicians, actually endangered their infants if they were not in good health (Censer, 1984; Child, 1837; McMillen, 1990; Schmidt, 1976; Fildes, 1986). Giuffra et al. (2015) note that the infant remains of the high-status Medici family during the Renaissance displayed extensive evidence of rickets. The authors associated these deficiencies with exclusive breastfeeding until 2 years of age delaying the use of supplementary foods in addition to swaddling increased risks of rickets. Newman & Gowland (2017) attribute the poor growth in high status individuals in industrial England to insufficient feeding practices during infancy that increased their susceptibility to infectious disease and malnutrition. Reedy (2021) report similar findings in a high status industrial-era London sample that exhibited similar rates of cribra orbitalia and porotic hyperostosis compared to lower status groups, suggesting their privileges did not buffer them from conditions such as intestinal parasites or vitamin deficiencies that cause anemia. Therefore, the benefits of high socioeconomic status may not buffer subadults who are the most vulnerable members of society from their environmental conditions.

Research questions

This research aims to compare the skeletal evidence of physiological stressors in urban and rural subadults to understand differential patterns of morbidity and mortality patterns in 18th-19th century eastern North Carolina. During this era of industrialization, urban areas were characterized by poor sanitary living and working conditions, pollution, and dense overcrowding, resulting in respiratory ailments, rampant disease from contaminated food and water sources, and epidemics (Brimblecombe, 1978; Brunton, 2013; Budnik & Liczbińska, 2006; Haines, 2001; Watson, 1987; Williams & Galley, 1995). Rural regions were idealized for the open landscapes and fresh air away from the pollutants of the city, but dense, crowded plantations in the swampy coastal regions of North Carolina were also plagued with infectious disease (McGuire & Coelho, 2020; McMillen, 1990; Watson, 1987). Weaning practices of nutritionally poor diets and contaminated food sources further heightened risk of death and disease in infants and children (Censer, 1984; Child, 1837; Fildes, 1995; McMillen, 1990; Schmidt, 1976). Bioarchaeological investigations reveal the complex interaction of biological and sociocultural factors impacting human health and development that challenge a binary divide of "worse" health outcomes in urban centers in contrast to "better" health in rural regions (Betsinger & DeWitte, 2021; Budnick & Liczbińska, 2006; Casna & Schrader, 2022; Crane-Kramer & Buckberry, 2020; DeWitte, 2014; Gowland et al., 2018; Lewis et al., 1995; Lewis, 2002; Lewis & Gowland, 2007; Mays et al., 2008; Mays et al., 2009; Newman & Gowland, 2017; Newman et al., 2019; Newman & Hodson, 2021; Reedy 2020; Veselka et al., 2015; Yaussy, 2019**).** There is a high degree of heterogeneity within and between contexts related to population demographics, environmental factors, and sociocultural customs and practices which encourages this research. In addition, there is a notable pattern of neonatal morbidity and mortality related to endogenous factors in rural environments compared to post-neonates associated with exogenous factors in urban environments (Budnick & Liczbińska, 2006; Landers, 1990; Lewis & Gowland, 2007; Ludlow & Hackett, 2019; Saunders et al., 2002; Vögele, 1994; Williams & Galley, 1995).

Previous bioarchaeological studies and historical evidence suggest that the Rhem family, who resided in the urban center of New Bern, will exhibit higher proportions of post-neonatal deaths and higher frequencies of physiological stressors including rickets, scurvy, carious lesions, cribra orbitalia/porotic hyperostosis, and linear enamel hypoplasias due to exposure to poor environmental conditions and use of insufficient weaning practices. In contrast, the rural Foscues are expected to exhibit higher proportion of neonatal deaths and lower frequencies of rickets, scurvy, carious lesions, cribra orbitalia/porotic hyperostosis, and linear enamel hypoplasias related to endogenous factors such as childbirth complications, congenital anomalies, and premature birth. This study aims to fill in the evident gap in urban-rural bioarchaeological research in the United States especially of high-status populations during the 18th and 19th centuries. This bioarchaeological data will be important for future comparative studies in North America and periods of industrialization.

CHAPTER THREE:

MATERIALS AND METHODS

Excavation methods

Excavation and documentation of the Rhem burial vault primarily occurred between June 1st and June 9th, 2021, followed by two final days of excavation on June 23rd and September 24th. The Rhem descendants, David French and Michael Miller provided us access to the vault and were present throughout the entirety of the excavation process. Additionally, an official from the North Carolina Department of Health and Human Services was onsite daily to monitor the potential public health risks of exhuming the coffins and remains from the vault.

Preliminary visits to the vault indicated that the roof's poor condition allowed precipitation to enter the burial vault interior, possibly over several years, and the vault interior showed extensive vine growth. The door to the entrance of the vault was on the east wall, and shelving units were located on the north and south walls with remnants of the collapsed wooden shelving showing termite and water damage. Two small, subadult iron coffins were at the door sill, and an adult wooden coffin was placed on top of an adult metal coffin in the middle section of the vault. On the southern shelf, a small, subadult coffin was on the top shelf above an adult metal coffin. Five small cast iron coffins were angled in various positions beneath the shelving units on the floor. On the north wall, three subadult cast iron coffins were also angled on top of one other on the vault floor. Coffins were clearly displaced from their original locations as seen from their placement on top of one another on the floor, and that one adult coffin was slid from one of the shelves onto the coffins in the center of the vault.

The vault presented a complex context, and thus several methods were employed for documentation and removal of the contents. First, the vault interior was photographed and mapped, documenting the position and location of the coffins and shelves. Intact or exposed coffins were treated as distinct features and were given unique identification numbers (F.01-F.19). Human remains and artifacts from vault deposits on the floor level were spatially grouped by Area (Areas A-F). In addition, clusters of human remains and artifacts within these areas some that could be associated with original wooden containers, were collected and labeled based on a feature number similar to the method used for coffins.

The recovery process began by removing two disturbed coffins from the door sill and the two coffins from the middle section of the vault followed by the seven coffins on the southern shelf and the three coffins on the northern shelf. Then, floor deposits containing human remains and artifacts were excavated by region in the vault. These floor deposits were photographed and measured to document their location in the vault. All soil from these contexts were sifted through quarter-inch mesh screens and artifacts and bones were documented and properly bagged. Underneath these contexts were layers of relatively sterile sand and brick rubble, of which only 33% was sifted.

CT scanning of coffins

Two of the intact subadult coffins, F.07 and F.06, were CT scanned at the East Carolina Heart Institute under the direction of CT Technologist, Susan Sandlin for preliminary assessment of the preservation and arrangement of the remains from a 3D perspective. The scans were produced by a Siemens Somatom Definition CT Scanner, using dual source technology which generated 0.6 mm scans of the coffins from frontal and sagittal orientations. For the settings, F.06 used 120 kilovoltage (kVp) and 650 milliampere-seconds (mAs), and F.07 used 120 kVp and 700 mAs due to its larger dimensions.

Opening coffins

The coffins were transported to two locations for documentation and analysis, the Phelps Archaeology Laboratory at ECU's Main Campus and the Queen Anne's Revenge (QAR) Conservation Laboratory on ECU's West Research campus. Each coffin was photographed and drawn to scale from top and profile views. The dimensions of the coffin and presence of associated hardware including handles, escutcheons, screws, and nails were also recorded (Stewart, 2022). All but two of the subadult cast iron coffins were opened by removing the screw heads by an angle grinder then drilling down through the screws with a carbide drill bit. The other two coffins were secured with screws through small extension brackets that extended horizontally from the coffins which were cut through directly using the cutting blade. Remains from the other two damaged and exposed coffins were documented and removed without opening the coffin. One of these coffins was composed of degraded wood in which the adult body was fully exposed in the vault and thus, the remains were collected while in the field. The adult metal coffins were in relatively good condition and were opened without the use of tools. Once opened, the interior of the coffins was photographed followed by excavation of the internal contexts in arbitrary layers to expose material and human remains. The coffin contents were then mapped, photographed, and removed for subsequent inventory and analysis. Finally, photos were taken of the coffin interior and the remaining debris was sifted.

Skeletal remains from the coffins and from the floor deposits were dry-brushed in the ECU Bioarchaeology Prep Laboratory using toothbrushes, paintbrushes, and wooden skewers and were analyzed in the ECU Bioarchaeology Lab. The commingled remains were relatively well-preserved with some taphonomic changes from rodent gnawing and surface exfoliation. The remains from the cast iron coffins varied in level of preservation. Because the seals of the cast iron coffins had deteriorated, environmental elements such as water, oxygen, and possible bacteria infiltrated the coffin interior and influenced the quality of preservation. Unidentified material, possibly corroded metal, encrusted the remains in some of the coffins. The remains could not be properly removed through careful brushing or lightly using water, nor could they withstand use of more invasive methods such as excavation using a Dremel bit. These remains were kept within the metal matrix, thus preventing further analysis of the remains from coffins in this study. Future assessment of these unique contexts may lead to effective methods and treatments to extract the remains. In many cases, the preservation of some materials within the cast iron coffins was remarkable, and some still contained clothing and coffin lining (Stewart, 2022) in addition to soft tissue and hair. However, the microenvironment within the clothing was detrimental to the preservation of the skeletal material, and in some cases only the skeletal elements not covered by the clothing were preserved well enough for analysis.

Osteological data collection

The commingled and articulated remains were inventoried using a FileMaker Pro 12.0 database structured for documentation of commingled remains (Osterholtz, 2019). Accession numbers were assigned to each diagnostic bone, and the original context, excavation date, date of inventory entry, initials of recorder, and individual identification number were recorded when applicable. Accession numbers consist of the Area or Feature number and the number of the bone in that section. For example, B.13 represents a bone from Area B and is the 13th bone recorded from the associated section. Identifiable bones were recorded as an individual entry in the database that also includes information about the side, degree of presence and fusion, pathology, measurements, and age and sex if possible. Highly fragmented cranial bones, ribs and unfused vertebral centra and neural arches were inventoried based on total count of pieces and assigned a single accession number for the collective fragments. Remains from coffins were assigned their feature number as their individual identification number and were not given accession numbers.

Age and sex estimation

Sex estimation of the adults relied on noting the presence/absence of a ventral arc, concavity of the subpubic angle, presence of the ischiopubic ramus ridge of the pubis region, and width of the greater sciatic notch (Phenice, 1969). Sex estimation of the skull followed Acsádi and Nemeskéri (1970) noting the robust and gracile features of the nuchal crest, mastoid process, supra-orbital margin, glabella, and mental eminence of the mandible. Sex estimation scores for adults were recorded as 0= indeterminate sex, 1= female, 2= probable female, 3= ambiguous sex, 4= probable male, 5= male. Sex estimation of subadults was not attempted due to the lack of sexually dimorphic features.

Age estimation of adults was determined through observing degenerative changes of the pubic symphysis, utilizing methods by Brooks and Suchey (1990) and Todd (1921) and alterations of the auricular surface using phases established by Lovejoy and colleagues (1985). Measurements of adult cranial and post-cranial measurements followed the dimensions listed by Moore-Jansen, Ousley, & Jantz (1994). Age estimation of subadults was based on developmental stage of bone growth and dental development. Measurements of the femur, fibula, tibia, radius, ulna, and humerus as well as the ilium, ischium, pubis, clavicle, and scapula were taken, and age estimated following the regression formulae of Cardoso, Abrantes, & Humphrey (2014) and Cardoso, Spake, and Humphrey (2017). Measurements of the basilar portion of the occipital and other cranial bones were used for age estimation following Scheuer & McLaughin-Black (1994) and Fazekas and Kosa (1978). Finally, age estimation also relied on fusion of primary and secondary ossification centers and stages of dental formation and eruption (AlQahtani, Hector, & Liversidge, 2010; Cunningham, Scheuer, & Black, 2016).

Individuation of commingled remains

Inventory of the adult and subadult commingled remains included attempts at individuation. Adult remains were grouped through pair-matching of bilateral elements, joint congruence, bone morphology and size, and evidence of pathological lesions such as joint degeneration. Each individual was assigned an individual identification number (e.g. "Individual 1", "Individual 2", etc.) that served to link together the associated elements that had been entered separately in the database. Additionally, the presence of skeletal elements and dentition of each adult individual were documented on forms of skeleton diagrams. These diagrams were not completed for subadult individuals due to the high number of fragmented elements.

Individuating the subadult commingled remains was limited due to the large number of individuals within the same age category and possible bias due to growth delay or disruption that could result in an incongruence in ages derived from long bone lengths, fusion of primary and secondary ossification centers, and dental development. Poor quality of preservation also impacted individuation of infant remains. For analysis, the remains were organized according to their age range as described above (preterm, birth – 1 year, 1 – 2 years, 3 – 6 years, 7 – 10 years, 11-18 years).

Skeletal and dental lesions

All of the bones and teeth were assessed for pathological lesions. Skeletal lesions including trauma, abnormal bone growth and loss, abnormal shape, and degenerative joint disease were documented macro- and microscopically. Pathologies were recorded following the protocol of Buikstra & Ubelaker (1994) for each applicable bone noting the location based on side, section of the bone, and aspect of the bone. Skeletal evidence of metabolic disease was documented following descriptions of Brickley et al. (Brickley & Mays, 2019; Brickley et al., 2020a; Brown, 2011; Brown & Ortner, 2011; Mays & Brickley, 2018; Ortner & Erickson, 1997; Ortner et al., 2001; Snoddy et al., 2018). Arthritis was recorded based on the degree and extent of bone lipping, surface porosity, eburnation, and surface osteophytes. Degenerative pathologies on the vertebral bodies were recorded according to the presence of Schmorl's nodes and degree of osteophytes. Abnormal new bone formation and loss or resorption were recorded based on location, extent, type of reaction, and whether it was active or healing/healed. Shape abnormalities were documented based on presence of bowing, metaphyseal flaring, and if the degree of shape abnormality was barely or clearly discernable. Evidence of porotic hyperostosis and cribra orbitalia was recorded based on degree of porosity and location and whether it was active or healing/healed.

All adult and deciduous teeth with visible tooth crowns were examined for linear enamel hypoplasias (LEH), caries, and calculus. Any associated alveolar bone also was observed for dental abscesses. Carious lesions were scored from 0-7 according to their location on the tooth and abscesses were scored from 0-2 based on the direction of the drainage channel (Moore and Corbett, 1971) and alveolar bone surface affected. Dental calculus was recorded according to the general amount of buildup on each tooth (Brothwell, 1981).

Overall, the excavation, recovery, and documentation of the coffins and remains from the Rhem burial vault was an extensive process. The exterior and interior contexts of the vault was documented followed by the removal of the coffins and excavation of the commingled remains. The coffins as well as their internal contents including the clothing and skeletal remains were photographed and recorded for proper inventory and analysis. Unfortunately, the poor preservation of the coffin remains prevented further analysis in this study. Commingled remains were individuated when applicable and were divided into appropriate age categories. Data collection of osteological remains involved identifying and siding elements, obtaining cranial and post-cranial measurements, estimating age and sex, and analyzing evidence of physiological stressors. Osteological data of the Foscue population was obtained from previous research (Seeman, 2011). These remains from the Rhem and Foscue sites with the use of the selected methodologies helps to assess potential differences in health and lifestyle of urban and rural environments in the southeastern U.S. during the 18th-19th centuries.

CHAPTER FOUR:

RESULTS

This chapter discusses the results of the archaeological excavation of the Rhem vault and the subsequent skeletal inventory and analysis of the Rhem remains, in addition to comparative analysis with the Foscue individuals. The excavation section details the vault dimensions and interior layout in addition to the spatial distribution of the coffins and commingled remains. The next section provides an overview of the Rhem and Foscue skeletal inventory and comparative analysis of age distribution and pathological frequencies. The Discussion chapter reviews the pathologies and age distribution of the Rhem Vault and Foscue Cemetery in relation to existing literature of urban-rural comparisons.

Archaeology of the Rhem Vault

The exterior of the Rhem burial vault consists of red-brick walls covered with stucco and a brownstone stepped-roof. A large urn was originally positioned on the roof but later fell off due to poor structural integrity. The exterior walls measure 9.8 ft. by 9.8 ft. and are 13.5 ft. height from the ground level to the top of the roof. The interior dimensions of the vault measure 7.4 ft by 7.4 ft, and the interior vault floor is 11.8 inches below the current ground level. The inner sill of the door measures 5.5 inches wide. Metal shelving units (7.4 ft x 1.5 ft.) line the entire face of the northern and southern walls and include expandable brackets that can be extended along the western wall. Each of the shelving units have five racks which are separated 1.5 ft. from one another, and the lowest rack is 1.5 ft. from the vault floor. Remnants of wooden shelf inserts had fallen from the racks due to their decay.

Figure 4.1. Interior of the Rhem burial vault from the door entrance. F.03, the adult coffin, is exposed and in the center of the vault while the subadult coffin, F.09 is closest to the door sill, and is adjacent to the fragmented segments of a subadult coffin (F.01 & F.04). The adult coffin, F.10 is visible on the upper left shelf rack. Photo by Dr. Megan Perry

The shelving system seemed to have contained nine coffins and caskets, although some had fallen as the wooden shelf inserts decayed and at least three were disturbed by looters (Figure 4.1). The middle of the vault floor contained two adult coffins, a mostly disintegrated wooden casket (F.03) positioned on top of an intact metal coffin (F.05). Adjacent to the inner door sill were two subadult coffins, a metal coffin fragmented into two pieces (F.01 & F.04) which were later identified as belonging to a single coffin, and a partially exposed iron coffin (F.02). The floor beneath the shelving unit of the north wall contained three subadult coffins, F.06, F.07, and F.08. These three coffins had fallen through the shelving unit, F.08 closer to the northeastern corner of the vault and F.06 and F.07 closer to the western end of the shelving unit (Figure 4.2). On the southern wall, two coffins, F.09 and F.10, coffins were still positioned on the shelfing unit while several others had clearly fallen through the shelves. F.10 was sitting on the second to top rack and F.09, a subadult iron coffin was lying on top of F.10. The bottom of F.10 at its head was torn open, which could have been from looting. The subadult iron coffins, F.11 and F.13 appeared to have fallen through the shelving racks as F.11 was angled diagonally on top of F.13 near the southeastern corner. In addition, F.12 had fallen on top of F.14 in the southwestern corner.

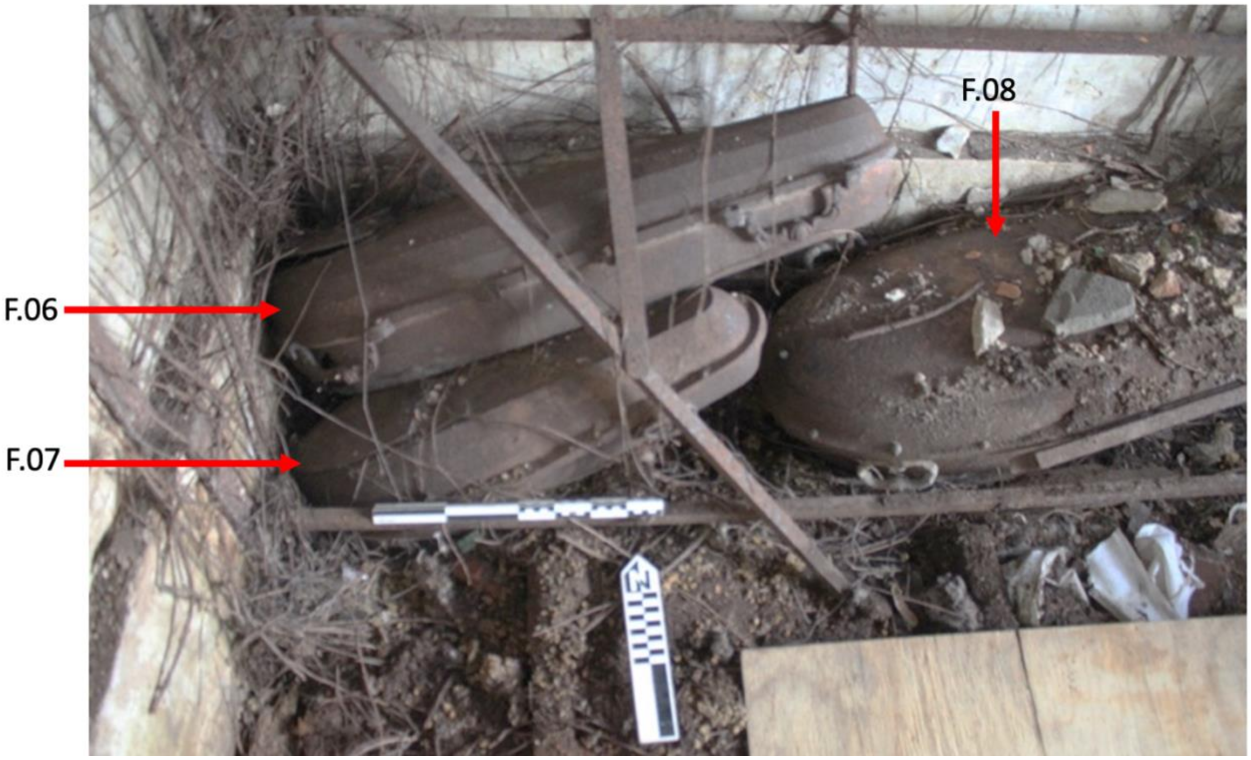

Figure 4.2. Subadult cast-iron coffins, F.06, F.07, and F.08 located on the north wall of the Rhem burial vault. Photo by Dr. Megan Perry.

The remains investigated here come from the uppermost of three soil layers that covered the entire vault floor. Directly on top of the vault floor was a 9.4 inch-thick layer of brick-andmortar rubble, probably from the original construction of the vault, and overlying this was 6.3 inches of sterile sand. These levels contain little material or skeletal remains perhaps due to their deposition before usage of vault, possibly in efforts to ameliorate the effects of flooding within the vault. The 6-8 inch-thick top level of soil and debris contained commingled skeletal remains, broken and mostly decayed pieces of wooden coffins with associated hardware and personal effects. A marble headstone was found lying face-down in the center of the vault at the bottom of this layer, and its associated footstone was found at the same level underneath the southern shelving unit. Some of these wooden coffin remnants and skeletal remains may have fallen due to disintegration of the wooden shelves although it is clear that some had been gathered and placed into wooden boxes that were placed under the shelving units.

In preparation for excavation, the vault floor was divided into different areas to control for the spatial distribution of the remains (Figure 4.3 & 4.4). Area A was the region between the lowermost central coffin F.05 and the southern shelving unit in the central section of the vault. Area B was underneath the southern shelving unit, and Area D was underneath the northern shelves. Area C refers to the portion of the central vault in between Area A and Area D. Two small probes within the northwestern and southeastern corners through the bottom-most rubble and sand layers were excavated as Area E, and these two layers throughout the rest of the tomb were excavated as Area F. Concentrations of human remains, some which were contained in wooden boxes, were identified as features within the Areas. Two features, F.15 and F.16, were identified within the western end of Area B. Evidence of a wooden container, F.15 was positioned directly above another wooden box, F.16. Area D in the northwestern corner contained two features with F.17 directly deposited above F.18. For more detailed information on the excavation areas, refer to Stewart (2022).

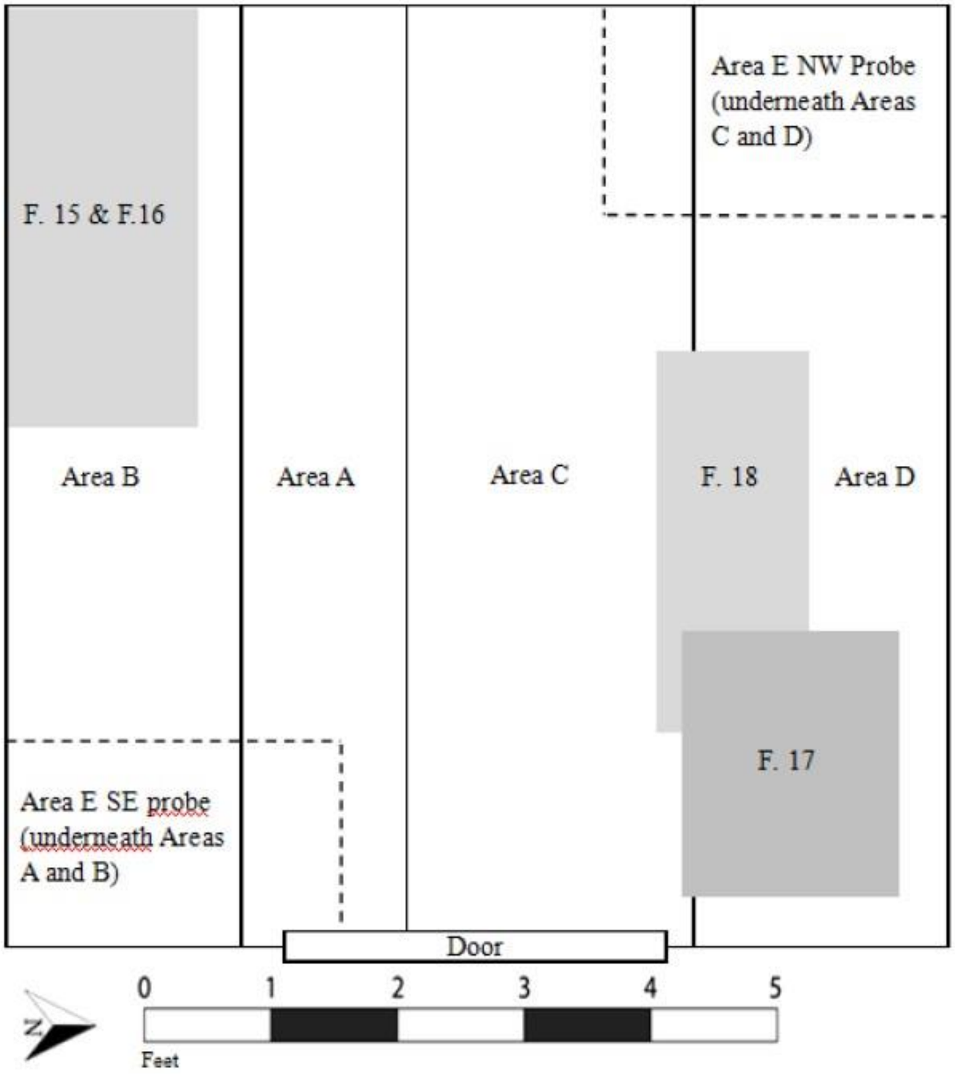

Figure 4.3. Map of the contexts in the Rhem Vault. Dashes indicate Features and Areas that were not present in all layers. Area F is not displayed in this map. It is the lowest layer in the vault and directly above the brick floor (Stewart, 2022).

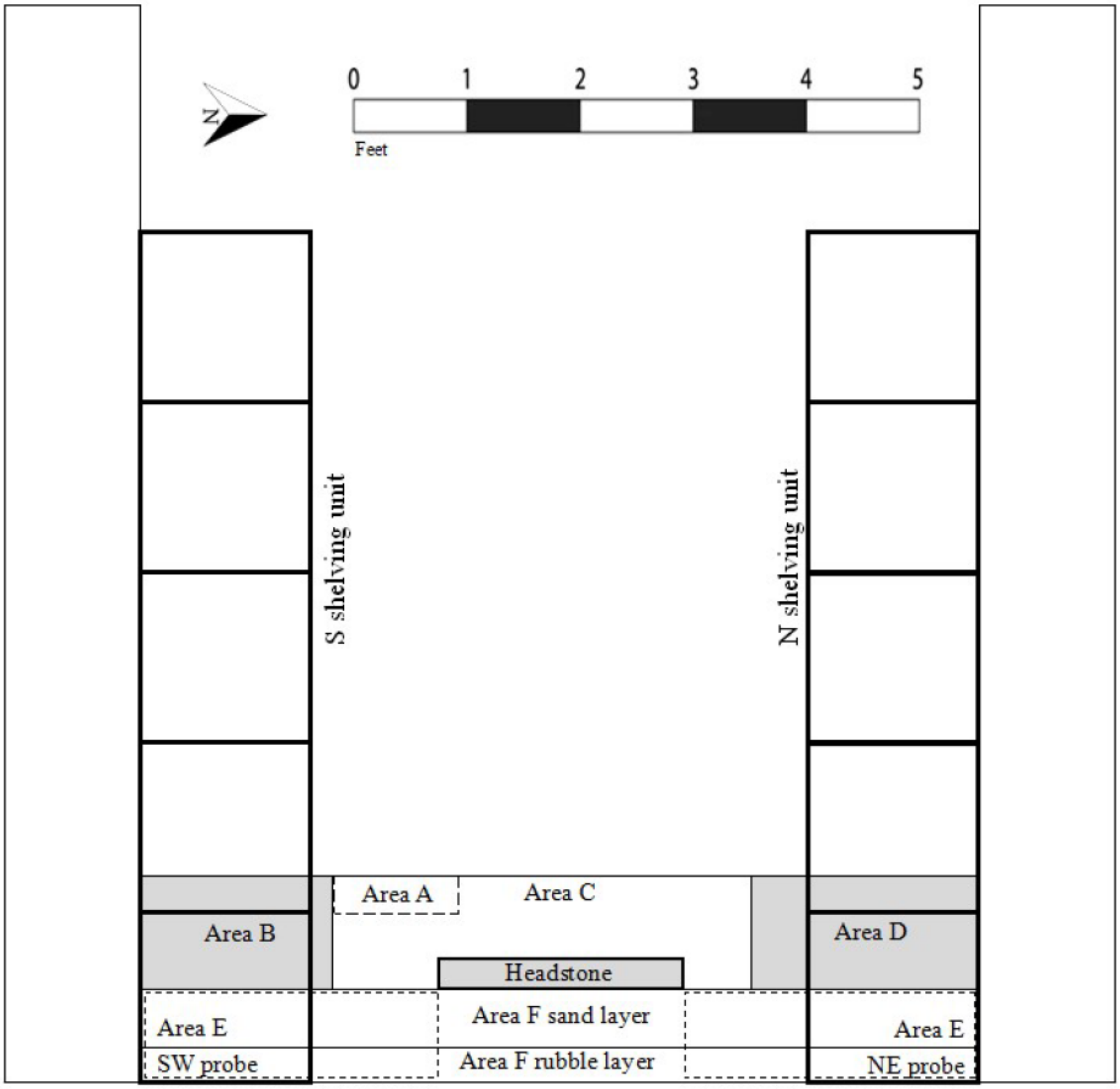

Figure 4.4. Western profile view of the Rhem Vault (Stewart, 2022).

Skeletal inventory and analysis

The skeletal remains from the floor deposits were inventoried and analyzed following methods in the previous chapter. The focus here is on subadult individuals (<18 years of age) to provide a picture of infant and childhood morbidity and mortality in the 18th-19th century southeastern U.S. The remains from the coffins and the commingled adults were excluded in this study.

Due to multiple individuals with similar estimated ages (particularly the birth to 1 year and 1 to 2 year age groups) and inter-element variation in growth and development rates, not all elements could be associated to a specific individual. Individuation of the subadult remains was possible for the single perinate and remains aged greater than 2 years old. Elements that could be individuated received sequential identification numbers, with Individuals 1 through 4 designating the adults and Individuals 5 through 10 representing the subadults. If individuation was not possible, the elements were assigned to a specific age category. As noted previously, the remains were divided into general age categories for inventory and analysis (preterm, birth to 1 year, 1 to 2 years, 3 to 6 years, 7 to 10 years, and 11 to 18 years). Element counts and frequencies of pathological lesions are presented by age category. Appendix B lists the methods and results of age estimation of the diagnostic elements, and Table 4.1 lists the minimum number of individuals by age category in the Rhem and Foscue vaults. In addition, Appendix A lists the total count of elements, or in the case of ribs, fragments for each age category. The MNI for each age class was calculated using a feature-based system based on a modified version of a FileMaker database for commingled remains developed by Osterholtz (2019). A total of 13 individuals were confirmed in the Rhem commingled subadult sample.

Table 4.1. Minimum number of subadult individuals in the Rhem* and Foscue vaults

Age Category	Rhem*	Foscue
Preterm	1	3
Birth-1 year	3	-
1-2 years	4	-
3-6 years	3	1
7-10 years	1	-
11-18 years	1	-
Total	13	4

*Rhem subadult sample only includes those from the commingled context.

Rhem Vault

Preterm

Individual 10: A minimum of one prenatal fetus is represented by 17 elements including the left scapula, right ulna, right greater wing of the sphenoid, right mandible, left petrous portion of the temporal, portions of the C2, C3-C7, and L1-L5 vertebrae, and 2 ribs. These elements all were found in the shallow pit F18 underneath the northern shelves in Area D. Age estimation of dental development and eruption was not possible due to the absence of associated teeth. The estimated ulna length of 47 mm established a gestational age of 32 weeks *in utero* for this fetus (Fazekas and Kosa, 1978).

Skeletal Pathology (Table 4.2)*:* Pathologies are limited to abnormal bone loss including multifocal porosity, measuring <1 mm in diameter. Porosity is centered around the foramen rotundum of the sphenoid and around the mylo-hyoid groove of the mandible. Porosity is also visible on the main foramen of the supraspinous and infraspinous fossa of the scapula.

Dental Pathology: Assessment of dental pathology was not possible due to the absence of observable teeth.

Table 4.2. Pathological lesions in perinatal individuals from the Rhem and Foscue vaults

Observation	Location	Rhem Vault		Foscue Vault	
		n/N	%	n/N	%
Abnormal bowing	Humerus	0/0	0.0%	0/3	0.0%
	Radius	0/0	0.0%	0/4	0.0%
	Ulna	0/1	0.0%	0/1	0.0%
	Femur	0/0	0.0%	0/6	0.0%
	Tibia	0/0	0.0%	0/4	0.0%
	Fibula	0/0	0.0%	0/0	0.0%
Metaphyseal Flaring	Humerus	0/0	0.0%	0/3	0.0%
	Radius	0/0	0.0%	0/4	0.0%
	Ulna	0/1	0.0%	0/1	0.0%
	Femur	0/0	0.0%	0/6	0.0%
	Tibia	0/0	0.0%	0/4	0.0%
	Fibula	0/0	0.0%	0/0	0.0%
Sternal end flaring	Ribs	0/0	0.0%	0/6	0.0%
Porosity	Frontal (orbital roof)	0/0	0.0%	0/0	0.0%
	Sphenoid (greater wing)	1/1	100.0%	0/0	0.0%
	Ribs	0/0	0.0%	0/6	0.0%
	Scapulae	1/1	100.0%	0/0	0.0%
	Ilium	0/0	0.0%	0/1	0.0%
	Humerus	0/0	0.0%	0/3	0.0%
	Radius	0/0	0.0%	0/4	0.0%
	Ulna	0/1	0.0%	0/1	0.0%
	Femur	0/0	0.0%	0/6	0.0%
	Tibia	0/0	0.0%	0/4	0.0%
	Fibula	0/0	0.0%	0/0	0.0%
Abnormal Bone Formation	Frontal (orbital roof)	0/0	0.0%	0/0	0.0%
	Scapulae	0/1	0.0%	0/0	0.0%
	Ilium	0/0	0.0%	0/1	0.0%
	Humerus	0/0	0.0%	0/3	0.0%
	Radius	0/0	0.0%	0/4	0.0%
	Ulna	0/1	0.0%	0/1	0.0%
	Femur	0/0	0.0%	0/6	0.0%
	Tibia	0/0	0.0%	0/4	0.0%
	Fibula	0/0	0.0%	0/0	0.0%
LEHs	Anterior dentition	0/0	0.0%	0/0	0.0%

Birth to 1 year

This age category includes individuals from birth to one year old and is comprised of 63 elements. A minimum of three individuals is established based on the presence of three right scapulae. Individuation of the elements was not possible due to the high count of commingled elements and high degree of fragmentation, although some elements could be pair-matched. These elements were found in the following vault contexts: Areas: A, B (including F.16), C and F.18 in Area D. Dental development and eruption and long bone length suggested an estimated age range of Birth -1 year (AlQahtani et al., 2010; Cardoso et al., 2014, 2017).

Skeletal Pathology (Table 4.3)*:* Shape abnormalities and localized areas of multifocal cortical porosity (<1 mm) and abnormal new bone formation (ANB) were visible on several of the elements. Porosity was visible on the superior and inferior sections of the palate and anterior portion of the left maxilla. Porosity was also recorded on the on the inferior aspect of the squamous portion of the occipital bone. Porous new bone formation consisting of reactive woven bone is present on the lateral aspect of the orbital roof of the frontal bone. Similar porous new bone formation is present on half (50.0%) of the left and right scapulae (Figure 4.6) and ulnae and half (50.0%) of the left ilia and 2/3rds (66.6%) of the left and right tibiae exhibited multifocal cortical porosity (<1 mm) extending from the growth plate proximally and distally. The scapular ANB is localized around the supraspinous fossa (Figure 4.6), and in the left and right ulnae near the ulnar tuberosities and nutrient foramina as well as on the posterior aspect of the proximal end. Pair-matched left and right tibiae display porosity extending proximally and distally from the growth plate with the proximal end exhibiting a sharp ridge (Figure 4.5) and a Pelkan spur, a bony growth resulting from healing of microfractures of poorly mineralized bone (Brickley & Mays, 2019; McCann, 1962). The left ilium exhibits porosity on the lateral and

Table 4.3. Pathological lesions in individuals from birth to 1 year of age from the Rhem vault (no remains from this age range were recovered from the Foscue vault)

Observation	Location	Rhem Vault	
		n/N	%
Abnormal bowing	Humerus	2/4	50.0%
	Radius	0/2	0.0%
	Ulna	2/4	50.0%
	Femur	1/3	33.3%
	Tibia	3/3	100.0%
	Fibula	0/1	0.0%
Metaphyseal Flaring	Humerus	2/4	50.0%
	Radius	0/2	0.0%
	Ulna	2/4	50.0%
	Femur	1/3	33.3%
	Tibia	2/3	66.7%
	Fibula	0/1	0.0%
Sternal end flaring	Ribs	0/4	0.0%
Porosity	Frontal (orbital roof)	1/1	100.0%
	Ribs	0/4	0.0%
	Scapulae	2/4	50.0%
	Ilium	1/2	50.0%
	Humerus	2/4	50.0%
	Radius	0/2	0.0%
	Ulna	1/4	25.0%
	Femur	0/3	0.0%
	Tibia	2/3	66.6%
	Fibula	0/1	0.0%
Abnormal Bone Formation	Frontal (orbital roof)	1/1	100.0%
	Scapulae	2/4	50.0%
	Ilium	0/2	0.00%
	Humerus	0/4	10.0%
	Radius	0/2	0.0%
	Ulna	1/4	25.0%
	Femur	0/3	0.0%
	Tibia	0/3	0.0%
	Fibula	0/1	0.0%
LEHs	Anterior dentition (Deciduous only)	0/4	0.0%

Figure 4.5. Accession number: B.65f. Age: 3.61 months (±3.48 months). Tibia displaying evidence of metaphyseal flaring and cortical porosity.

Figure 4.6. Accession number: B.53b. Age: 4-8 months. Cortical porosity and abnormal new bone formation surrounding the supraspinous foramen of the scapula.

posterior sides of the acetabulum and near the greater sciatic notch. Shape abnormalities including a combination of metaphyseal flaring and abnormal bowing appears on half (50.0%) of the humerii and ulnae and a third (33.3%) of the femora. All of the tibiae (100.0%) present evidence of abnormal bowing, but only 66.7% of the tibiae show metaphyseal flaring (Figure 4.5).

Dental Pathology: No dental pathologies are present.

1 to 2 years old

This category represents non-adults aged from 1 to 2 years old and contains 202 elements. There is a minimum of four individuals based on the presence of four left ilia. Individuation of the elements was not possible due to the similarities in estimated age of the commingled elements and high degree of fragmentation. Elements of this age category are associated with the following contexts in the vault: Area B (including F.16), Area C, and Area D (including F.17 and F.18). Dental development and eruption, long bone diaphyseal lengths, and shoulder and pelvic girdle measurements yielded an estimated age range of 1-2 years (AlQahtani et al., 2010; Cardoso et al., 2014 & 2017).

Skeletal Pathology (Table 4.4)*:* Shape abnormalities, multifocal cortical porosity (<1 mm), and abnormal new bone formation are visible on the elements. Several of the long bones present shape abnormalities. Abnormal bowing and metaphyseal flaring are visible on 40% of the radii and 25% of the tibiae (25.0%), while half of the ulnae (50.0 %) and less than half of the femora (40.0%) display only metaphyseal flaring. On the cranial bones, porosity is localized around the external auditory meatus of the temporal bone and new bone formation is present on the squamous portion.

Porosity was present on half of the scapulae (50.0%), and a quarter of the tibiae (25.0%), and ilia (25.0%). Porosity and sternal end flaring were visible on almost a third of the ribs (32.1%). Abnormal new bone formation was limited to only one left ilium (25.0% of all iliae).

Table 4.4. Pathological lesions in individuals aged 1-2 years from the Rhem vault (no remains from this age range were recovered from the Foscue vault)

Observation	Location	Rhem Vault	
		n/N	%
Abnormal bowing	Humerus	0/6	0.0%
	Radius	2/5	40.0%
	Ulna	1/2	50.0%
	Femur	2/5	40.0%
	Tibia	1/4	25.0%
	Fibula	0/5	0.0%
Metaphyseal Flaring	Humerus	0/6	0.0%
	Radius	2/5	40.0%
	Ulna	0/2	0.0%
	Femur	0/5	0.0%
	Tibia	1/4	25.0%
	Fibula	0/5	0.0%
Sternal end flaring	Ribs	9/28	32.1%
Porosity	Frontal (orbital roof)	0/2	0.0%
	Ribs	9/28	32.1%
	Scapulae	1/3	33.0%
	Ilium	1/4	25.0%
	Humerus	0/6	0.0%
	Radius	0/5	0.0%
	Ulna	0/2	0.0%
	Femur	0/5	0.0%
	Tibia	1/4	25.0%
	Fibula	0/5	0.0%
Abnormal Bone Formation	Frontal (orbital roof)	0/2	0.0%
	Scapula	0/3	0.0%
	Ilium	1/4	25.0%
	Humerus	0/6	0.0%
	Radius	0/5	0.0%
	Ulna	0/2	0.0%
	Femur	0/5	0.0%
	Tibia	0/4	0.0%
	Fibula	0/5	0.0%
LEHs	Anterior dentition	0/1	0.0%

Dental Pathology: No dental pathologies were noted in these individuals.

3 to 6 years old

This category contains nonadults aged from 3 to 6 years old and includes 371 elements. There is a minimum number of three individuals based on the presence of three left temporal bones from the cranial bones. Differences in the ages of the individuals allowed for individuation of most of the remains into Individuals 7, 8, and 9**.** The elements were found in the following contexts: around F.14, F.15 and F.16 in Area B, Area C, and F.17 and F.18 in Area D. Table 4.5 summarizes the frequency of pathological lesions in these individuals.

Individual 7: Fusion of cranial sutures, dental development and eruption, and long bone length yielded an age range of 5-6 years for this individual (AlQahtani et al., 2010; Cardoso et al., 2014, 2017; Cunningham et al., 2016). The skull is complete and most of the cranial sutures are fully fused with the exception of the spheno-occipital synchondrosis and the basilar portion of the occipital bone. Several post-cranial elements, such as right and left humerii, ulnae, femora, tibiae, and all pelvic bones, and a right scapula, radius, and fibula were linked to this individual.

Skeletal Pathology: This individual presents several pathologies on the post-cranial elements. Abnormal bowing and metaphyseal flaring are both present on the right radius and right ulna while both sets of the left and right tibiae and femora only show evidence of metaphyseal flaring. The right fibula has abnormal bowing, and abnormal new bone formation is visible on the left ilium.

Dental Pathology: One lesion of interproximal caries is present on the deciduous mandibular left first molar (Lm$_1$).

Individual 8: Due to the absence of the dentition, the estimated femur length of 181 mm established an estimated age range of 3-4 years old (Cardoso et al., 2014). Only right and left clavicles, femora, and tibiae could be linked to this individual.

Table 4.5. Pathological lesions in individuals aged 3-6 years old from the Rhem and Foscue vaults

Observation	Location	Rhem Vault		Foscue Vault	
		n/N	%	n/N	%
Abnormal bowing	Humerus	0/5	0.0%	0/0	0.0%
	Radius	1/4	25.0%	0/0	0.0%
	Ulna	1/4	25.0%	0/0	0.0%
	Femur	2/6	33.3%	0/1	0.0%
	Tibia	2/6	33.3%	0/1	0.0%
	Fibula	2/2	100.0%	0/1	0.0%
Metaphyseal Flaring	Humerus	0/5	0.0%	0/0	0.0%
	Radius	1/4	25.0%	0/0	0.0%
	Ulna	1/4	25.0%	0/0	0.0%
	Femur	2/6	33.3%	0/1	0.0%
	Tibia	0/6	0.0%	0/1	0.0%
	Fibula	0/2	0.0%	0/1	0.0%
Sternal end flaring	Ribs	0/58	0.0%	0/0	0.0%
Porosity	Frontal (orbital roof)	0/2	0.0%	0/2	0.0%
	Ribs	0/58	0.0%	0/0	0.0%
	Scapulae	0/1	0.0%	0/0	0.0%
	Ilium	1/5	20.0%	0/1	0.0%
	Humerus	0/5	0.0%	0/0	0.0%
	Radius	0/4	0.0%	0/0	0.0%
	Ulna	0/4	0.0%	0/0	0.0%
	Femur	0/6	0.0%	0/1	0.0%
	Tibia	0/6	0.0%	0/1	0.0%
	Fibula	0/2	0.0%	0/1	0.0%
Abnormal Bone Formation	Frontal (orbital roof)	0/2	0.0%	0/2	0.0%
	Scapula	0/1	0.0%	0/0	0.0%
	Ilium	0/5	0.0%	0/0	0.0%
	Humerus	0/5	0.0%	0/1	0.0%
	Radius	0/4	0.0%	0/0	0.0%
	Ulna	0/4	0.0%	0/0	0.0%
	Femur	0/6	0.0%	0/0	0.0%
	Tibia	2/6	33.3%	0/1	0.0%
	Fibula	0/2	0.0%	0/1	0.0%
LEHs	Anterior dentition (Permanent and deciduous)	5/5	100.0%	0/0	0.0%

Skeletal Pathology: Periostitis was noted on the left and right tibia on the anterior aspect of the shafts.

Dental Pathology: Assessment of dental pathology was not possible due to the absence of teeth.

Individual 9: Dental age estimation, long bone length, and fusion of primary and secondary ossification centers resulted in age range of 4-5 years (AlQahtani et al., 2010; Cardoso et al., 2014, 2017; Cunningham et al., 2016). The present cranial elements include the left and right maxillae, left temporal, frontal bone, sphenoid, and basilar portion of occipital bone. Sets of right and left humerii, ulnae, radii, ilia, femora, and tibiae and a left fibula could be matched to this individual.

Skeletal pathology: Multifocal porosity (<1 mm) penetrating the periosteal surface is present on the orbital roofs of the frontal bone. Abnormal bowing is present on the right and left femora and the left fibula.

Dental Pathology: Interproximal caries are present on the deciduous maxillary left second molar (Lm^2) and mandibular right second molar (Rm_2).

7 to 10 years old

Individual 6: A minimum of one individual is represented in this age category with a total of 75 elements. These elements were found in the following contexts: Area B, including F.15 and F.16, Area C, and Area D including F.18. Dental age estimation yielded a refined age of 8-10 years for the maxillae and 7-8 years for the mandible (AlQahtani et al., 2010). The lengths of the long bones including the humerii: 193 mm and the femora (265 mm) also yielded an age of approximately 8 years (Cardoso et al., 2014). Most of the skeletal elements are present in this category except for Ribs 1, Ribs 2, and Rib 12.

Skeletal Pathology (Table 4.6): The only present pathology is evidence of multifocal porosity (<1 mm) penetrating the periosteal surface on the orbital roof of the frontal bone.

Dental Pathology: Multiple dental pathologies are present on the dentition. A total of four linear enamel hypoplasias are present on the anterior dentition of five teeth (Appendix C). Two hypoplasias are visible on the maxillary right canine (RC^1) and three are present on the mandibular right lateral incisor (RI_2). The earliest age of occurrence is 2.12 years based on the distance from the CEJ of 4.50 mm on the right mandibular lateral incisor (RI_2), and the latest age of occurrence is 3.75 years based on the distance from the CEJ of 3.60 mm on the right maxillary canine (RC^1) (Henriquez & Oxenham, 2019). Interproximal caries are present on both of the deciduous mandibular left second molar (Lm_2) and the mandibular right second molar (Rm_2).

Table 4.6. Pathological lesions in individuals aged 7-10 years in the Rhem vault (no remains from this age range were recovered from the Foscue vault)

Observation	Location	Rhem Vault	
		n/N	%
Abnormal bowing	Humerus	0/1	0.0%
	Radius	0/2	0.0%
	Ulna	0/2	0.0%
	Femur	0/2	0.0%
	Tibia	0/2	0.0%
	Fibula	0/2	0.0%
Metaphyseal Flaring	Humerus	0/1	0.0%
	Radius	0/2	0.0%
	Ulna	0/2	0.0%
	Femur	0/2	0.0%
	Tibia	0/2	0.0%
	Fibula	0/2	0.0%
Sternal end flaring	Ribs	0/5	0.0%
Porosity	Frontal (orbital roof)	2/2	100.0%
	Ribs	0/5	0.0%
	Scapulae	0/2	0.0%
	Ilium	0/2	0.0%
	Humerus	0/1	0.0%
	Radius	0/2	0.0%
	Ulna	0/2	0.0%
	Femur	0/2	0.0%
	Tibia	0/2	0.0%
	Fibula	0/2	0.0%
Abnormal Bone Formation	Frontal (orbital roof)	0/2	0.0%
	Ilium	0/2	0.0%
	Humerus	0/1	0.0%
	Radius	0/2	0.0%
	Ulna	0/2	0.0%
	Femur	0/2	0.0%
	Tibia	0/2	0.0%
	Fibula	0/2	0.0%
LEHs	Anterior dentition (Permanent and deciduous)	2/2	0.0%

11 to 18 years old

Individual 5: A minimum of one individual is represented in this age category by a total of 115 elements. These elements were found in the following contexts: Area B, including F.16, Area A, and Area D. Most of the elements are present for this individual with the exception of the sphenoid, the mandible, and a few cervical vertebrae. Dental development and eruption, long bone length, and fusion of primary and secondary ossification centers yielded an age range of 12.5-14.5 years old (AlQahtani et al., 2010; Cardoso et al., 2014, 2017; Cunningham et al., 2016).

Skeletal Pathology (Table 4.7)*:* The only present pathologies are cribra orbitalia on both the left and right eye orbits of the frontal bone.

Dental Pathology: Several dental pathologies are present on the dentition. All of the present permanent canines and incisors display linear enamel hypoplasias except for the lower right first incisor (RI_1) which is missing postmortem. A total of 33 linear enamel hypoplasias are present on 11 observable anterior teeth (Appendix C). The earliest age of occurrence ranges from 4.32 months or 0.36 years (9.12 mm from the CEJ) on the left maxillary central incisor (LI^1) and the latest age of occurrence is 4.88 years based on the distance from the CEJ of 2.68 mm on the left mandibular canine (LC_1) ((Henriquez & Oxenham, 2019). Occlusal caries are present on the permanent mandibular left first and second molars (LM_1 and LM_2) and the permanent mandibular right first molar (RM_1).

Table 4.7. Pathological lesions in individuals aged 11-18 years in the Rhem vault (no remains from this age range were recovered from the Foscue vault)

Observation	Location	Rhem Vault	
		n/N	%
Abnormal bowing	Humerus	0/2	0.0%
	Radius	0/2	0.0%
	Ulna	0/2	0.0%
	Femur	0/2	0.0%
	Tibia	0/2	0.0%
	Fibula	0/2	0.0%
Metaphyseal Flaring	Humerus	0/2	0.0%
	Radius	0/2	0.0%
	Ulna	0/2	0.0%
	Femur	0/2	0.0%
	Tibia	0/2	0.0%
	Fibula	0/2	0.0%
Sternal end flaring	Ribs	0/9	0.0%
Porosity	Frontal (orbital roof)	1/2	50.0%
	Ribs	0/9	0.0%
	Scapulae	0/2	0.0%
	Ilium	0/2	0.0%
	Humerus	0/1	0.0%
	Radius	0/2	0.0%
	Ulna	0/2	0.0%
	Femur	0/2	0.0%
	Tibia	0/2	0.0%
	Fibula	0/2	0.0%
Abnormal Bone Formation	Frontal (orbital roof)	0/1	0.0%
	Ilium	0/2	0.0%
	Humerus	0/2	0.0%
	Radius	0/2	0.0%
	Ulna	0/2	0.0%
	Femur	0/2	0.0%
	Tibia	0/2	0.0%
	Fibula	0/2	0.0%
LEHs	Anterior dentition (Permanent and deciduous)	11/11	100.0%

Foscue Vault

Osteological data from the Foscue vault was presented in Perry et al., in press and Seeman, 2011 and is summarized here for comparison to the Rhem vault. Counts of elements associated with each age group is included in Appendix A.

Preterm

A minimum of three individuals were identified as belonging to this age category based on dental development and postcranial measurements, consisting of a total of 31 elements. Dental age estimations of the individuals yielded the similar ages of eight months (31-32 weeks) in utero.

Skeletal Pathology (Table 4.2)*:* No significant skeletal pathologies were present.

Dental Pathology: No significant dental pathologies were present.

3 to 6 years old

A minimum of one individual is represented in this age category by a total of 26 elements. Dental development established an estimated age range of 3 (± 12 months) years.

Skeletal Pathology (Table 4.5)*:* No significant skeletal pathologies were present.

Dental Pathology: Although linear enamel hypoplasias were not present, several caries were visible. Interproximal caries were noted on the right central incisor and left first molar and mandibular right central incisor, right lateral incisor, right canine, left central incisor, and left canine. Occlusal caries were identified on the maxillary right second molar, mandibular right first and second molars and the left first and second molars. One buccal cavity was noted on the mandibular left first molar.

Comparing age-at-death distributions

In the Rhem population, subadults of both coffin and commingled contexts comprise most of the total population (77.0%, 24/31). In the commingled context, most of the subadults are aged >1 year old (61.5%, 9/13) with four individuals aged 1-2 years old, three individuals aged 3-6 years old, one individual aged 7-10 years old, and one individual aged 12.5-14.5 years old. The lower proportion of individuals aged <1 year old (30.8%, 4/13) may be due to preservation issues resulting in an underrepresentation of infants that will be discussed further in the following chapter. In the Foscue population, nearly half of the total population consists of subadults (44.4%, 4/9) with the highest percentage of subadults being fetuses and/or neonates aged 31-36 gestational weeks (75.0%, 3/4) while the oldest subadult is 3 years old (Perry et al., in press).

Comparisons of pathological lesions in the Rhem and Foscue vaults

There is limited comparable data regarding physiological stressors in Foscue population due to its smaller sample size. In general, the children from the urban Rhem family died with greater evidence of physiological stressors than the rural Foscue population. Linear enamel hypoplasias were the most frequent non-specific indicator of stress in the Foscue population, with 4 out of 20 (20.0%) of the permanent and deciduous anterior dentition exhibiting at least one LEH. In the Rhem population, 13 of a total 64 permanent and deciduous anterior teeth (4.69%) in two individuals showed evidence of at least one hypoplasia indicating multiple periods of stress in both individuals. The age of occurrence for one Rhem individual ranged from 1.5-4.6 years old, and 2.2-3.0 years old in the other individual. In the Foscue population, Perry et al., in press note that the age of occurrence of one Foscue individual was aged to 3-5 years old.

The other Foscue individual showed evidence of stress at the age of 2.6 years old. Dental caries was also present in both subadult populations. The 3-year-old individual from the Foscue population showed extensive dental decay in which 12 out of the 17 teeth exhibited caries (71%). In the Rhem population, dental decay was present in only one of the subadults (4-5 years old) with a total of 8 caries on the 30 (26.7%) deciduous teeth present.

Skeletal manifestations of metabolic disease and non-specific indicators of stress were only present in the urban Rhem population. Several elements exhibited evidence of rickets, scurvy, anemia, and potential infection. In the birth-1 year old category, at least 33% of the elements exhibited signs of rickets including metaphyseal flaring, metaphyseal porosity, and abnormal bowing. Evidence of scurvy was present in this age category on half (50%) of the elements based on the presence of porosity and new bone formation on the scapulae. The single neonate also showed signs suggestive of scurvy based on porosity on the greater wing of the sphenoid and the main foramen of the infraspinous and supraspinous fossa of the scapula. In the 1-2 year and the 3-6 year categories, around 25%-50% of the elements exhibited signs of rickets. In the 3-6 year old category, approximately 25%-33% of the elements showed signs of rickets. Sternal end flaring of the ribs was also present (8.7%, 9/104). Porosity on the metaphyses and on the sternal end of ribs was also visible indicating active rickets and/or scurvy and/or anemia. Although these lesions may suggest evidence of scurvy and/or rickets, signs of abnormal new bone formation can also be associated as a response to infection and trauma, thus consideration of other factors should be taken into account. Evidence of cribra orbitalia was only present on the single adolescent (12.5-14.5 years old).

Summary

Excavation and analysis of the Rhem vault contents evidence of 14 coffins each containing a single individual and 19 commingled individuals of which the 13 commingled subadults were the focus of this study. These subadults range in age from perinate to adolescent (12.5-14.5 years of age) with the highest number of individuals (four) aged from 1 to 2 years of age. Rhem subadults presented extensive evidence of non-physiological stressors including rickets, scurvy, cribra orbitalia/porotic hyperostosis, linear enamel hypoplasias, and dental caries. In comparison, the Foscue subadults including three neonates and one child, 3 (± 12 months) years of age only exhibited stressors of linear enamel hypoplasias and dental caries. The age-at-death mortality data indicate that the Foscue infants were more susceptible to death due to endogenous factors during the perinatal period than the Rhem children, whose age-at-death data indicate a greater impact of exogamous factors on mortality.

CHAPTER FIVE:

DISCUSSION

As evident in the previous chapter, the urban Rhem and rural Foscue children experienced early life adversities of metabolic disease and other physiological stressors in the 18th-19th century southeastern U.S. This chapter discusses the evidence of metabolic disease and mortality rates in relation to their contemporary environmental contexts and infant and child care-taking practices, incorporating similar urban-rural bioarchaeological and historical literature to illustrate patterns of morbidity and mortality risks of this period. Furthermore, this section highlights differential health risks of endogenous or exogenous factors dependent on the age of the subadults, and the relationship of the mother-infant nexus and the first 1000 days of life on health outcomes in early life stages.

Evidence of physiological stressors and age-at-death mortality from the urban Rhem and rural Foscue populations reflect the original expectations of this study. The low neonatal mortality rate and the prevalence of physiological stressors including scurvy, rickets, porotic hyperostosis/criba orbitalia, linear enamel hypoplasias, and caries of the Rhem group confirm initial hypotheses expecting a greater influence of exogenous factors impacting urban morbidity and mortality patterns. Meanwhile, the Foscue group did not exhibit any significant pathologies and displayed a higher neonatal mortality rate compared to the urban population, thus demonstrating a greater effect of endogenous factors on rural morbidity and mortality patterns. These findings are important for illuminating health disparities of urban-rural contexts during this period which will be discussed further in this chapter.

The urban and rural commingled subadult populations have small sample sizes (Rhem: N=13 and Foscue: N=4), limiting broader comparisons between these two branches of the family. However, demographic and paleopathological patterns can be compared to understand the morbidity and mortality risks of urban versus rural environments in the U.S. during a period of endemic infectious disease, poor sanitary conditions, rampant air pollution, and limited medical knowledge. This research provides insight into the differential mortality and morbidity risks of an extended family living in urban and rural environments in 18th-19th century eastern North Carolina.

Demographic composition and mortality bias

The demographic composition of the Rhem and Foscue subadult populations may signify the high infant and childhood mortality of the 18th and 19th century in the United States. The total Rhem sample is composed of 31 individuals: 3 adults and 11 subadults found within intact coffins, which will not be covered further here, and 4 adults and 13 subadults found in commingled contexts, which the subadults will be the focus of this discussion. The youngest subadult in the commingled assemblage is a perinate (36 gestational weeks of age) followed by three individuals aged from birth to 1 year old, four individuals aged from 1 to 2 years old, and three individuals aged from 3 to 6 years old, and finally, one adolescent individual aged from 12.5-14.5 years old. The Foscue sample consists of 9 individuals, including 5 adults and 4 subadults, all from a commingled assemblage. Three of the subadults are perinates (31-36 gestational weeks of age), and the fourth subadult is 2 to 4 years old (Perry et al., in press). There is not only a difference in the representation of subadults in the Foscue sample (n=4 out of 9 individuals, 44% of the total sample) compared to the subadults from the Rhem commingled sample (13 out of 17 individuals, or, 76% of the total sample), but also variation in the ages represented in each sample. Is this disparity due to different patterns of infant mortality? Or other factors, such a variation in preservation or fertility rates?

The difference in sample sizes and age representation between the populations could indicate a sampling bias due to an underrepresentation of rural infants as a result of poor preservation. However, the environments within the two brick-lined vaults with brick floors likely did not differ significantly, since both vaults were in areas with a high-water table and possible flooding. The primary difference is that less soil covered the remains in the Rhem vault than in the Foscue vault. In addition, the similarity in cortical bone erosion and element representation suggests that differential preservation likely was not a factor for the underrepresentation of infants in the Foscue vault.

The differences in ages-at-death could indicate that factors related to intrauterine conditions, congenital anomalies, and childbirth complications were likely the highest cause of mortality in the Foscues. Perinatal (24 gestational weeks to 7 post-natal days) and neonatal (birth to 28 days) mortality is often due to endogenous factors related to maternal health and intrauterine conditions, while deaths of children over the age of 1 month are associated with exogenous factors related to environmental conditions and the weaning period (Bourgeois-Pichat, 1951; Lewis, 2007; Lewis & Gowland, 2007).

Three out of four of the subadult individuals (or 75%) in the Foscue family vault are perinates compared to the one perinate from the Rhem vault, representing only 9% of the commingled subadult sample. This higher concentration of perinates in the rural population could indicate higher mortality risks related to endogenous factors associated with the *in utero* environment or with childbirth itself. In the Rhem vault, the presence of multiple individuals past the age of 1 month would that indicate external mortality risks played a larger role in infant and childhood deaths.

Bioarchaeological and demographic studies of urban versus rural contexts also found a greater number of post-neonatal deaths (>1 month) in urban areas compared to rural areas during periods of rapid industrialization (Cullen & Owsley, 2011; Saunders et al., 2002; Landers, 1990, Vögele, 1994, Budnick & Liczbińska, 2006; Williams & Galley, 1995). In a study of an urban elite population in 19th century Canada, Saunders et al. (2002) notes a higher percentage of post-neonates (74%) than neonates (26%) which they linked with the effects of poor sanitary conditions exacerbating risk of infectious disease and malnutrition associated in the industrialized environment. Budnick & Liczbińska (2006) found higher rates of post-neonatal mortality in urban centers than rural regions in 19th century Polish populations. Demographic reports link high mortality rates of respiratory disease, dysentery, and diarrhea to poor sanitary conditions in the urban, industrialized centers. The high number of Rhem subadults over the age of 1 month suggests there were higher mortality risks in this family associated with environmental factors and the weaning period (Lewis & Gowland, 2007) than related to endogenous factors.

Studies have also found high infant mortality related to the weaning period, which increases infant susceptibility to disease and malnutrition due to the transition from breastmilk to solid foods (Herring, Saunders, & Katzenberg, 1998; Katzenberg et al., 1996; Lewis, 2007; Newman & Gowland, 2017). Weaning age in 18th and 19th century North America varied, with comparative historical and isotopic studies indicating that weaning could commence anywhere between 3 months to 12 months of age and lasting until 22 months (Child, 1837; Herring et al., 1998; McMillen, 1990; Schmidt, 1976; Taylor, 2020). However, isotopic evidence from an 18th to 19th century sample from eastern North Carolina indicates that the weaning period on average began around 6 months and ceased at 1.5 years of age, although some individuals completed weaning between 2 and 4 years (Taylor, 2020). Most of the Rhem infants who died were between 1 to 2 years of age which may be attributed to the stress of weaning.

Finally, differences in fertility rates could have caused the variation in infant and childhood mortality between the Foscue and the Rhem vaults. Demographers have long recognized that age-at-death mortality patterns are more impacted by demographic nonstationarity rather than true age-related mortality (McFadden, Muir, & Oxenham, 2022; Sattenspiel & Harpending, 1983). Therefore, higher fertility in the Rhem family due to either greater individual parity or a larger number of child-bearing individuals associated with the vault could have resulted in higher proportion of infant deaths throughout the timespan of the vault's usage, thus significantly impacting the number of infants in the sample. Based on the Rhem family history, variations in their family structure were most likely more impactful on infant mortality than general demographic changes. Thus, increased fertility amongst the Rhems due to increased longevity or fecundity of childbearing family members and greater numbers of individuals at childbearing age could have impacted age-at-death mortality profiles, especially during a historical period of high childbirth rates.

Mothers during the 18th to 19th centuries were praised for raising large families and anywhere between five and eight children per family on average was considered the norm (Kennedy, 2012; McMillen, 1990; Withycombe, 2019). Women began bearing children in their late adolescence or early twenties, and upper-class families in urban areas often relied on physicians although obstetric knowledge was limited (Withycombe, 2019). According to genealogical records, Rhem, Sr.'s first wife, Anne Kilpatrick (1831-1853) gave birth to three children when she was between the ages of 18-21 years old (1 out of 3 died, 33.3%), and his second wife, Sarah Catherine Tucker (1835-1880) gave birth to 12 children (7 out of 12 died, 58.3%) when she was between the ages of 22 and 41 years (*Joseph L. Rhem Family Bible,* 1860/2020). Although the commingled subadults in the Rhem vault cannot be directly linked to these genealogical records, the two child-bearing individuals, Anne Kilpatrick and Sarah Catherine Tucker, and the high number of births represents the influence of high fertility on the age-at-death mortality profile. Finally, the number of child-bearing individuals who would have buried their infants and young children in the family vaults might have differed. For instance, genealogical evidence suggests some of the Foscues dispersed to other locations with their children being buried in locations other than the family vault in Pollocksville (Foscue, 1895; Perry et al., in press).

Mother-infant nexus and first 1000 days of life

The morbidity and mortality risks of the urban Rhem and rural Foscue families may illustrate the interconnected relationship of the mother-infant nexus and the significance of the first 1000 days of life (Barker et al., 1993; Gowland, 2018; Gowland & Halcrow, 2020; Kinshella, Moore, & Elango, 2021; Schwarzenberg et al., 2018). As previously discussed, the first 1000 days of life (conception to 2 years of age) represents a critical window of rapid growth and development during the pre and early post-natal period. Adequate nutrition during this period is necessary for sufficient immunity and somatic development, and due to the demands of rapid growth, there is also heightened susceptibility to intrauterine and environmental adversities causing increased risks of malnutrition (Barker et al., 1993; Kinshella et al., 2021; Schwarzenberg et al., 2018). Depending on the health status, maternal transmission of immunological and nutritional buffering also influences fetal/infant health and developmental outcomes (Gowland & Halcrow, 2020).

External factors of environmental conditions and weaning practices also impact health and developmental trajectories. Sordid urban environments including unsanitary living/working conditions, air pollution, contaminated food and water sources, and overcrowding have shown to exacerbate these health risks during the industrial era (Ellis, 2016; Hodson & Gowland, 2020; Gowland et al., 2018; Newman & Gowland, 2021). During this period, nutritionally poor weaning diets comprised of bread, broth, and animal's milk, further increased risks of malnutrition and thus, infectious disease due to their synergistic relationship (Child, 1837; McMillen, 1990). Likewise, differential evidence of nutritional deficiencies and maternal passive immunity between the urban Rhem and rural Foscue subadults reflects this sensitive period of rapid growth and development and the influence of maternal health.

It is well-known that maternal passive immunity in utero and via breastmilk provides extensive nutritional and immunological benefits to infants depending on the health status of the mother (Ballard & Marrow, 2013; Binns, Lee, & Low, 2016; Hodson & Gowland, 2020; Miller, 2020; WHO, 2021). While in utero, the fetus is supplied with micronutrients including vitamin C and vitamin D from the mother, which continues through breastfeeding in lower concentrations; thus, transitioning to food sources poor in nutrients may result in nutritional deficiencies as weaning progresses as seen in the Rhem infants (Brickley et al., 2020a; Dawodu, Agarwal, Hossain, Kochiyil, & Zayed, 2003; Pearce & Cheetham, 2010). Studies have noted that exclusive breastfeeding of 6 months is linked with greater adaptability of the infant's gut microbiome to new food sources, therefore decreasing risks of inflammation and infectious diseases (Binns et al., 2016; Granger et al., 2021; Miller, 2017;Thompson et al., 2015; WHO, 2021). Unlike human breastmilk, cow's milk, commonly used in 18th-19th century weaning practices, does not contain the same nutrients and bioactive factors such as the immunoglobulins, sIgA and IgG characterized by their antimicrobial and anti-inflammatory properties. In addition, cow’s milk increases inflammatory risks in infants due to the presence of lactose, potential allergen-causing proteins, and microbial pathogens responsible for infections (Al-Beltagi, Saeed, Bediwy, & Elbeltagi, 2022; Ballard & Morrow, 2013).

Human breastmilk contains high concentrations of vitamin C depending on the nutritional status of the mother, but has lower quantities of vitamin D, thus adequate sunlight exposure is necessary for nursing mothers and infants (Ballard & Morrow, 2013; Brickley et al., 2020a; German Nutrition Society, 2015). Because of the heightened need for vitamin C during pregnancy and breastfeeding, mothers are at a higher risk of vitamin C deficiency especially if they have malnourished diets (Brickley et al., 2020a; Hirschmann & Raugi, 1999). Evidence suggestive of scurvy in the Rhem perinate may reveal the presence of adult scurvy in the mother while the presence of metabolic disease in the older infants may indicate suppressed post-natal nutritional buffering and immunity via breastmilk (Hodson & Gowland, 2020; Lewis, 2010; Snoddy et al., 2017).

Skeletal and dental evidence of metabolic disease

Overall, the urban Rhem infants and children displayed greater evidence of metabolic disease than the rural Foscue subadults. The Foscue perinates and child did not exhibit any significant pathologies. Meanwhile evidence of scurvy was visible in the Rhem perinate and in 50.0% of the scapulae of those individuals less than 1 year of age. Rickets was present in 66.0% of tibiae of infants less than 1 year of age and in 50.0% of the ulnae of infants from 1 to 2 years of age. The older Rhem children from 3 to 10 years of age presented limited evidence of rickets, and the single adolescent only exhibited signs of cribra orbitalia/porotic hyperostosis. Linear enamel hypoplasias were present in both the urban Rhem and rural Foscue populations. In the

Rhem population, the age-at-defect formation ranges from 1.5 years to 4.6 years of age, indicating evidence of early childhood stress. Most of the defects develop between 2.0-4.9 years old (82%; 28/34 LEHs) with the average age-at-defect formation being 3.0 years old. In the Foscue population, the age of occurrence of hypoplasias was also 2 to 5 years old (Perry et al., in press). The prevalence of metabolic disease in Rhem group especially among the perinate and infants is most likely associated with their sordid urban living conditions, insufficient weaning strategies, and potential maternal health. In contrast, the lack of skeletal pathologies in the Foscue perinates and child may suggest protection via passive maternal immunity and greater mortality risks associated with childbirth complications. These results suggest differential health risks of urban and rural contexts related to environmental factors and contemporary sociocultural practices which impacted those of even high-status backgrounds.

Evidence of exogenous factors

The high prevalence of rickets and scurvy among the Rhem infants and children may indicate evidence of inadequate weaning practices implemented by elite families during the industrial era. Although high socioeconomic status generally entails greater health outcomes than those of impoverished backgrounds, studies of this period indicate that affluent families utilized inadequate weaning strategies, increasing risks of ill health and malnutrition for infants and children (Giuffra et al., 2015; Lewis, 2002; Newman & Gowland, 2017; Newman et al., 2019; Saunders et al., 1995). In a study of 18th-19th century English populations, Newman & Gowland (2017) found high crude prevalence rates of rickets and scurvy in high-status subadults between the ages of 1 to 5 years. The authors associate this peak in metabolic disease with contemporary weaning practices and infant/child-rearing strategies which increased susceptibility to their deleterious urban conditions. During the 18th and 19th centuries, the weaning process was highly stressful for the health of infants especially with the risk of contaminated food sources and unsanitary environmental conditions (Censer, 1984; Fildes, 1986; McMillen, 1990). High-status families transitioned away from breastfeeding and instead, initiated weaning at younger ages (Censer, 1984; Fildes, 1986; McMillen, 1990). The onset of weaning could begin as early as 4 months of age or as late as 22 months while current WHO guidelines recommend 6 months of exclusive breastfeeding (Censer, 1984; Lewis, 2007; McMillen, 1990; Taylor, 2020). The weaning diet during this period consisted of "pap", bread and cow's or goat's milk and/or "panada", cereal and broth which are both high in fats and carbohydrates but low in quantities of vitamin C and vitamin D (Child, 1837; McMillen, 1990; Stevens, Patrick, & Pickler, 2009). Physicians during this period advised against frequent consumption of meat, vegetables, and fruit among children to avoid abdominal discomfort and also dissuaded pregnant mothers from eating vegetables and "fermented liquors" which could "sour" their breastmilk (Child, 1837). Additionally, infants also faced risks of gastrointestinal diseases including dysentery and "cholera infantum" also known as "summer diarrhea" due to the seasonality of the disease usually associated with contaminated food and milk sources (Child, 1837; McMillen, 1990).

Evidence of dental enamel hypoplasias during early childhood is also an indirect indicator of malnutrition and infectious disease continuing past the weaning age. Although the presence of hypoplasias is present later than the general weaning range, several studies have reported a similar pattern of higher LEH frequencies in later development (Blakey et al., 1994; Corruccini et al., 1985; Dąbrowski et al., 2021; Goodman & Armelagos, 1985; King, Humphrey, & Hillson, 2005; Temple, 2020). Since only the permanent dentition exhibited hypoplastic lesions, the earliest age-at-defect formation will only appear after the first year of age as crown formation of the permanent anterior teeth does not commence until 1.0-1.8 years of age (Reid & Dean, 2000). Most hypoplasias will not be visible from macroscopic observations until 2 years of age due to appositional layers of enamel, and that hypoplasias are deeper and more defined in the intermediate and cervical regions of the cusp than the occlusal region (2-4 years) (Hillson & Bond, 1997; Goodman & Armelagos, 1985; Guatelli-Steinberg, Floyd, Dean, & Reid, 2012). Studies have commonly associated the presence of enamel hypoplasias with weaning practices of nutrient poor foods and contaminated food sources that increases mortality and morbidity risks of infants (Goodman et al., 1987; Katzenburg et al., 1996). In addition, in a study of 17th-18th century English populations, Gowland et al. (2018) reported enamel defects which was associated with vitamin D and/or calcium deficiencies spanning from in utero to 2 years of age, suggesting poor maternal and child health. Vitamin D deficiencies result in reduced mineralization, impacting proper enamel development (Brickley et al., 2020a; Goodman & Armelagos, 1985). Due to the small sample size, comparisons cannot be made between presence of LEHs on deciduous versus permanent teeth.

The conditions of urban, industrial environments during this period may also explain the prevalence of rickets in the Rhem subadults. Similar cases have reported limited sunlight exposure due to pollution production from industries (Ellis, 2010; Ives, 2018; Lewis, 2002; Mays & Brickley, 2018; Mays, Brickley, & Ives, 2006; Newman & Gowland, 2017; Schmidt, 1976; Zhang et al., 2016). Studies of 18th-19th century England report industrial emissions and coal smoke from homes reducing sunlight exposure especially during the winter season (DeWitte et al., 2016; Ives, 2018; Lewis, 2002; Newman & Gowland, 2017; Newman et al., 2019). Newman et al. (2019) notes higher rates of rickets among children especially those aged 1 to 5 years from sites of northern England compared to those in southern regions. The authors suggest that the higher northern latitudes and pollution generated by the industrial factories, diminished sufficient levels of sunlight exposure and thus, resulted in greater risk of vitamin D deficiencies. The Rhems may also have experienced reduced access to sunlight necessary for adequate levels of vitamin D as the city of New Bern also contained several manufacturing industries including turpentine distilleries, tanneries, sawmills, and textile plants, responsible for producing air pollution (Watson, 1987).

Another factor possibly associated with the high rates of rickets in the Rhems is insufficient infant and child-rearing strategies that restricted their access to sunlight. Ellis (2010) reported a high proportion of rickets (34.0% of the tibiae) among infants and children of 19th century New York City. The author notes the limited hours of sunlight exposure in the city especially during the winter season and even higher risks for individuals confined to the indoors such as homes, schools, and workplaces possibly facilitated vitamin D deficiencies. Middle and high-status English families during the industrial-era restricted their children access to the outdoors to avoid “moral or physical contamination” (Newman & Gowland, 2017). Swaddling infants was also a common practice especially during the winter season in protection from the cold, further reducing access to sunlight (Ellis, 2010; Giuffra et al., 2015; Newman & Gowland, 2017). Some clinical studies recommend approximately 5 to 30 minutes of sunlight exposure daily or at least twice a week (with a nutritional diet) although the Rhem infants and children may have not experienced this due to confinement indoors (Holick, 2005; National Institutes of Health, 2022).

Cribra orbitalia and porotic hyperostosis were only present in the adolescent and have several etiologies linked with genetic and nutritional-deficient anemias also in co-occurrence with metabolic diseases, parasitic infections, and immune responses to bacterial infections

(Brickley, 2018; Godde & Hens, 2021; McIlvaine, 2010; Oxenham & Cavill, 2010; Rivera & Lahr, 2017; Walker et al., 2009). Even though status should serve as a health buffer, studies have discovered similar rates of cribra orbitalia and porotic hyperostosis between high status and low status groups in industrialized contexts (Godde & Hens, 2021; Reedy, 2021; Yaussy, 2019). Reedy (2021) found that the high-status 18th-19th century London group exhibited comparable rates of cribra orbitalia and porotic hyperostosis to lower status groups, suggesting elite groups were still susceptible to malnourishment, infectious disease, and poor urban conditions. These results may indicate that the privileges of high status did not always serve as a barrier to the detrimental effects of industrialized environments and poor diets.

Evidence of endogenous factors

In contrast, the notable absence of pathologies in the Foscue subadults may suggest a greater role of endogenous factors in morbidity and mortality risks including childbirth complications possibly related to poor obstetric practices of this period. The Foscues who died in infancy do not show skeletal evidence of physiological stressors; however, their young age would suggest any potential deficiencies or infections before death could have been buffered by maternal passive immunity and nutritional buffering (Hodson & Gowland, 2020; Palmeira, Quinello, Silveira-Lessa, Zago, & Carneiro-Sampaio, 2011; Pierzynowska et al., 2020). Maternal passive immunity provides protection from pathogens through the transfer of maternal antibodies such as the predominant immunoglobulin, IgG across the placenta to the fetus as early as the 13th week of gestation with the highest load during the final 4 weeks of pregnancy (final trimester), lasting for up to 6 months or longer in infants through breastfeeding (Hoshower, 1994; McDade, 2003; Palmeira et al., 2011). Passive immunity has been referred to as “immunological imprinting" in which the maternal antibodies are based on maternal antigenic experiences which can also be affected by stressors from earlier life stages, thus impacting infant immunity (Lemke & Lange, 1999; Miller, 2020).

Historical records indicate that one of the Foscue daughters, Christiana, died during childbirth, and it was hypothesized that she died giving birth to twins, represented by two of the perinates (Perry et al., in press). The other infant was born to Julia Foscue Sanderson and reportedly died shortly after birth (Perry et al., in press). Mortality during childbirth was common during the 19th century due to the lack of medical knowledge in proper obstetric practices and prenatal health care (Censer, 1984; McMillen, 1990). Additionally, pregnant mothers were highly susceptible to infectious diseases including malaria due to mosquito-infested swamp environments in rural areas which endangered the health of the fetus (McMillen, 1990; Sobhy, Babiker, Zamora, Khan, & Kunst, 2017; Thompson et al., 2014). Even though urban and rural planter families had access to physicians, rural families relied more on the assistance of midwives and family members for childbearing (Kennedy, 2012; McMillen, 1990). Thus, deaths related to labor complications were common in rural, households as mortality during the first year of life was generally between 115 and 313 per 1000 births (Brunton, 2013; Censer, 1984; Kennedy, 2012; McMillen, 1990).

Etiology of dental caries

The Foscues and Rhems subadults exhibited high frequencies of dental caries during their childhood (Foscue- 71.0%, Rhem- 40.0%). The 2-4 year old of the Foscue population and the four subadults ranging from 4 years old to 14.5 years old from the Rhem population presented extensive dental decay. Dental caries is linked with an over-proliferation of bacteria in the oral cavity and has a synergistic relationship with LEHs, in which the reduced mineralization makes the dentition susceptible to acidic decay (Larsen, 2018; Vargas-Ferreira et al., 2015). Consumption of high-carbohydrate foods is linked with increased risk of dental caries as well as genetic variation in amelogenesis and oral ecology and diversity of the oral microbiome (Larsen, 2018; Lukacs, 2011). Isotopic evidence indicates that adult and children's diets during this period in North Carolina consisted of high amounts of maize and sugar products as well as marine resources and plant products (Taylor, 2020). Caries in children may result from this excessive consumption of sweets or poor enamel. Mothers with caries also have a high likelihood of their children also developing caries (Silk et al., 2008). While dentists promoted proper oral hygiene through regular tooth brushing maintenance during the 18th- 19th centuries, dental care was still rudimentary and dental problems were common (Schmidt, 1976). Hosek, Warner-Smith, & Watson (2020) note high rates of caries in a 19th century New York population related to the poor urban environment leaving the lower classes malnourished and high consumption of sugar due to the low prices. Additionally, in a study comparing post-medieval sites in England, Lewis (2002) found that urban and industrialized populations of upper to middle class backgrounds had higher rates of dental caries and abscesses than the rural populations. This evidence of poor dental care further indicates mortality and morbidity risks of urban and rural environments. Bruwelheide et al. (2020) note the prevalence of caries associated with carbohydrate-rich diets in enslaved and free African and/or African American populations of 18th-19th century mid-Atlantic regions. The authors note how food sources derived from corn were staples in Southern diets, thus demonstrating these high rates of caries which may also reflect those in the Rhem subadults.

Implications

Overall, the subadults of the urban Rhem and rural Foscue populations exhibited the expected high morbidity and mortality risks of infants and children in the 18th-19th century southeastern U.S. The high frequency of Foscue perinates in the subadult sample (3/4; 75%) with no significant pathologies suggests high mortality risks of endogenous factors including possible non-skeletal congenital abnormalities, complications with childbirth, and poor maternal health conditions. In the Rhem population, evidence of metabolic disease especially in those greater than 1 month old indicates high morbidity and mortality risks related to exogenous factors of environmental factors and cultural practices. The weaning period overlaps with this age range indicating the susceptibility of infants to their environmental surrounding due to the cessation of breastfeeding and transition to nutrient-poor foods also increasing malnourishment and risk of infection. The morbidity and mortality risks of subadults during the early stages of the life course also highlights the influence of maternal health on subadult growth and development. Evidence suggestive of scurvy in the Rhem perinate indicates possible poor nutritional health of the mother while the perinates of the Foscue population exhibited no pathologies, suggesting they were protected in utero from pathogens by maternal passive immunity.

CHAPTER SIX:

CONCLUSION

The morbidity and mortality patterns of the Rhem and Foscue populations reveal the differential exogenous and endogenous health risks of urban and rural environments in 18th and 19th century North Carolina, respectively. This skeletal evidence also reflect the deleterious health and lifestyle conditions characterizing this period as described in related bioarchaeological and historical literature (Budnick & Liczbińska, 2006; Censer, 1984; Cullen & Owsley, 2011; Cummings and Roxbury, 1851; Gowland et al., 2018; Landers, 1990; McMillen, 1990; Newman & Gowland, 2018; Newman & Hodson, 2021; “Sanitary”, 1862; Saunders et al., 2002; Schmidt, 1976; “The Sickness in New Berne”, 1864; Taylor, 2020; Trinkley & Hacker, 2015; Vögele, 1994; Williams & Galley, 1995). The Rhem group exhibits high rates of infant and childhood mortality (13 out of 17 individuals, or, 76%) and evidence of metabolic diseases, suggesting that their wealth did not buffer these children from the effects of poor nutrition and infection. The highest mortality rates were present in those between 1 to 2 years of age (4 out of 13, or, 31%), when infants are more exposed to exogenous factors leading to poor health and malnutrition, including the possible effects of improper weaning practices or weaning-related conditions. Isotopic analysis and historical evidence from this context suggest that weaning could commence as early as 3 months of age and end at 1.5 years of age on average but could extend to 2.5 to 4.5 years of age (McMillen, 1990; Taylor, 2020). Current studies suggest that weaning should commence from 4 to 6 months of age and cease at 2 years of age or older, suggesting that weaning stressors may have not played the largest factor in later childhood mortality and maternal passive immunity may have continued to serve as a buffer from exogenous factors (Miller, 2020; WHO, 2021). Skeletal evidence of scurvy and rickets and formation of linear enamel hypoplasias in the Rhem infants also indicate nutritionally poor diets during weaning, which heightened their susceptibility to malnutrition and infection. This evidence also indicates that the social privileges of high status did not completely buffer the Rhems from their squalid urban environment.

In comparison, endogenous factors of childbirth complications, possible congenital anomalies, and poor maternal health exhibited a greater influence in mortality and morbidity patterns in the rural Foscue population. High mortality of Foscue neonates (75%; 3/4) compared to the Rhem perinate (9%; 1/13) suggests a greater association with health complications during labor as also supported by the family records (Perry et al., in press). Obstetric practices during the 18th-19th century were still rudimentary, and planter families mostly relied on the assistance of local midwives and family members (Censer, 1984; McMillen, 1990; Schmidt, 1976). The lack of pathologies also suggests the perinates were protected from pathogens via maternal passive immunity during gestation. However, formation of LEHs occurred from 2 to 5 years of age in one Foscue individual similar to the age range of the Rhems, indicating potential stressors throughout childhood although development of hypoplasias is linked with multiple etiologies. Therefore, the high mortality of neonates and absence of physiological stressors in the Foscue group may reflect greater health risks due to endogenous factors such as complications during labor rather than adverse environmental conditions in rural settings.

The unique patterns of morbidity and mortality in these urban and rural groups highlight the significance of the mother-infant dyad and the first 1000 days of life. Evidence of metabolic disease in the Rhem infants and children suggest that maternal passive immunity and nutritional buffering from breastmilk less effectively protected infants from their adverse urban surroundings (Hodson & Gowland, 2020; Miller, 2020). As previously mentioned, the absence of pathologies in the perinates of the Foscue group may indicate that the mother had optimal dietary intake during pregnancy which did not hinder the health and nutritional status of the fetus, even though the still did not survive much if at all beyond birth. Thus, this study reveals the differential impact of urban and rural contexts during the 18th-19th centuries on the mother-infant interface.

This investigation represents one of the few bioarchaeological studies of urban-rural contexts in the United States. These findings provide unique insight into the health and lifestyles of high-status urban and rural families in eastern North Carolina during a period of rampant disease and squalid urban conditions. Findings from this study could be applied to future urban-rural studies of modern populations to reveal potential shifts in health outcomes over time. These studies could also highlight how the effects of social status have changed health disparities between past and modern urban-rural populations. This analysis also highlights the interwoven nature of the mother-infant nexus in understanding the maternal transmission of nutritional deficiencies and immune protection the fetus/infant and the intergenerational impact of environmental and sociocultural factors. Ultimately, this research will enrich the limited bioarchaeological literature of comparative urban-rural studies in the United States and will provide further insight into the relation of the mother-infant interface for future studies.

Future research

Life course approaches and additional macroscopic analysis

Future investigations should incorporate similar macroscopic analyses of skeletal stressors and growth disruption to expand the health profile of the urban population. Furthermore, analysis of other pathological lesions such as tuberculosis and maxillary sinusitis associated with respiratory infections will continue to expand the detrimental health effects of urban living and industrialization (Boyd, 2020; DiGangi and Sirianni, 2017; Gowland et al., 2018; Lewis et al., 1995). Evidence of growth disruption can be assessed through long bone metaphyseal length and vertebral dimensions of the body and neural canal plotted against age of dental eruption (Gowland et al., 2018; Mays et al., 2008; Newman et al., 2019). With further inventory and analysis of the Rhem adults, skeletal evidence of early life adversities including linear enamel hypoplasias, stunted long bone length, and small vertebral dimensions, should be assessed to understand morbidity and mortality risks in adulthood. This life course approach to bioarchaeological analysis emphasizes intergenerational dynamics of health and disease rather than the experiences of malnutrition and infection restricted to an individual's life history (Agarwal, 2016; Barker et al., 1993; Gowland, 2015; McDade, 2003). Furthermore, there should also be skeletal analysis of associated mother-fetal/infant individuals from the Rhem group to indicate potential evidence of similar pathologies highlighting maternal transmission of health and the physiological impact of sociocultural and environmental factors of future generations (Gowland & Halcrow, 2020; Hodson & Gowland, 2020; Snoddy et al., 2017).

Isotopic and histological analysis of dentition and bone collagen

Isotopic and histological analyses are useful tools to reconstruct the health and diet of the Rhem population (Beaumont et al., 2018; Brickley et al., 2020b; D'Ortenzio et al., 2016; Halcrow, Miller, Pechenkina, Dong, & Fan, 2021; Tsutaya & Yoneda, 2015). The prevalence of Rhem subadult skeletal and dental remains of various ages is suitable for nitrogen and carbon isotope analysis which can be tested on bone and dentin collagen and hair and nail keratin. Hair and nail samples were also recovered from subadults interred in coffins. Nitrogen isotope analysis can assist in reconstruction of breastfeeding and weaning practices based on elevated $\delta^{15}N$ values indicating the start of breastfeeding and declining values noting the onset of the weaning process (Beaumont et al., 2018; Tsutaya & Yoneda, 2015). With carbon isotope analysis, heightened values of $\delta^{13}C$ in infants compared to the mother reveal use of exclusive breastfeeding, and $\delta^{13}C$ values can also differentiate weaning foods from those of adult diets depending on the difference in isotopic composition (Beaumont et al., 2018; Tsutaya & Yoneda, 2015). Metabolic changes resulting from severe malnutrition, infectious disease, and trauma can generate elevated $\delta^{15}N$ signatures in hair keratin, further unveiling their health status (D'Ortenzio, Brickley, Schwarcz, & Prowse, 2015; Mora, 2022). Isotopic analyses can further enrich the health profiles and dietary intake of the Rhem group for future urban-rural comparative studies and investigations related to socioeconomic status during the 19th century.

Evidence of vitamin D deficiency was visible in several of the Rhem subadult skeletal elements. Future investigations of vitamin D deficiencies should integrate histological analysis of interglobular dentin (IGD) using the first permanent molars and deciduous dentition to identify past episodes of vitamin D deficiency (Brickley et al., 2020b; D'Ortenzio et al., 2016; Veselka et al., 2019). The age of occurrence is based on the location of IGD which can be correlated to the approximate age when tooth mineralization occurs during the stages of dental development (D'Ortenzio et al., 2016). Unlike macroscopic examinations, these results of histological analysis can show previous repeated episodes of deficiency potentially associated with seasonal patterns of sunlight exposure inhibited by swaddling practices and/or with infectious disease and malnutrition lowering immunity or preventing absorption of critical nutrients (Veselka et al., 2019). Incorporating histological analysis can strengthen assessment of vitamin D deficiencies in individuals especially if skeletal evidence is limited (D'Ortenzio et al., 2016). These findings can also identify prenatal and postnatal episodes based on IGD location to the neonatal line, uncovering possible maternal nutritional deficiencies and highlighting the relationship of the mother-infant dyad (Brickley et al., 2020b; Veselka et al., 2019). Furthermore, histological analysis in combination with stable isotope analysis can reveal vitamin D deficiencies resulting from nutritionally insufficient weaning foods (Taylor, 2020). Histological analysis will further highlight the health and nutritional status of the Rhem population.

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APPENDIX A: FREQUENCY OF RHEM SKELETAL ELEMENTS

Rhem: Preterm

Element	**Total (N)**	**L**	**R**
Frontal	0	0	0
Parietal	0	0	0
Temporal	1	1	0
Occipital (squamous)	0	0	0
Occipital (basilar)	0	0	0
Zygomatic	0	0	0
Maxilla	0	0	0
Nasal	0	0	0
Sphenoid	0	0	0
Mandible	1	0	1
C1	1	0	1
C2	2	1	1
C3-C7: Neural arches	1	1	0
C3-C7 centra	0	0	0
T1-T12: Neural arches	5	3	2
T1-T12 centra	3	-	-
L1-L5: Neural arches	3	1	2
L1-L5 centra	0	0	0
Sacrum	0	0	0
Rib 1	0	0	0
Rib 2	0	0	0
Ribs 3-10	0	0	0
Rib 11	0	0	0
Rib 12	0	0	0
Ribs (indeterminate side)	0	0	0
Scapula	1	1	0
Clavicle	0	0	0
Sternum	0	0	0
Humerus	0	0	0
Radius	0	0	0
Ulna	1	0	1
Ilium	0	0	0
Ischium	0	0	0
Pubis	0	0	0
Femur	0	0	0
Tibia	0	0	0
Fibula	0	0	0

“-“, indicates the element was not sided

Rhem: Birth-1 year

Element	N	L	R
Frontal	1	0	1
Parietal	1	1	0
Temporal	0	0	0
Occipital (squamous)	2	1	1
Occipital (basilar)	2	-	-
Zygomatic	4	2	2
Maxilla	2	1	1
Nasal	0	0	0
Sphenoid	0	0	0
Mandible	2	1	1
C1	2	1	1
C2	0	0	0
C3-C7: Neural arches	3	3	0
C3-C7 centra	1	-	-
T1-T12: Neural arches	7	3	4
T1-T12 centra	5	-	-
L1-L5: Neural arches	3	1	2
L1-L5 centra	0	-	-
Sacrum	0	-	-
Rib 1	1	0	1
Rib 2	0	0	0
Ribs 3-10	11	6	5
Rib 11	0	0	0
Rib 12	0	0	0
Ribs (indeterminate side)	1	-	-
Scapula	4	1	3
Clavicle	2	1	1
Sternum	0	0	0
Humerus	4	2	2
Radius	2	2	0
Ulna	4	2	2
Ilium	2	1	1
Ischium	1	0	1
Pubis	1	1	0
Femur	3	1	2
Tibia	3	1	2
Fibula	1	1	0

Rhem: 1-2 years

Element	**N**	**L**	**R**
Frontal	3	1	2
Parietal	1	1	0
Temporal	1	1	0
Occipital (squamous)	1	0	1
Occipital (basilar)	1	-	-
Zygomatic	1	1	0
Maxilla	2	1	1
Nasal	0	0	0
Sphenoid	0	0	0
Mandible	5	3	2
C1	3	2	1
C2	2	1	1
C3-C7 neural arches	11	6	5
C3-C7 centra	0	0	0
T1-T12 neural arches	13	5	8
T1-T12 centra	9	-	-
L1-L5 neural arches	24	12	12
L1-L5 centra	0	-	-
S1-S5	0	0	0
Rib 1	5	4	1
Rib 2	6	2	4
Ribs 3-10	60	26	34
Rib 11	0	0	0
Rib 12	2	1	1
Ribs 1-12 (indeterminate side)	8	-	-
Scapula	3	2	1
Clavicle	5	2	3
Sternum	0	-	-
Humerus	6	3	3
Radius	5	3	2
Ulna	2	1	1
Ilium	4	4	0
Ischium	4	2	2
Pubis	1	0	1
Femur	5	2	3
Tibia	4	3	1
Fibula	5	2	3

Rhem: 3-6 years old

Element	**N**	**L**	**R**
Frontal	4	2	2
Parietal	4	2	2
Temporal	5	3	2
Occipital fused	2	1	1
Occipital (basilar)	1	-	-
Occipital (lateral)	2	1	1
Zygomatic	3	2	1
Maxilla	4	2	2
Nasal	2	1	1
Sphenoid	5	2	3
Mandible	5	2	3
C1	6	3	3
C2	6	3	3
C3-C7: neural arches	29	15	14
C3-C7: centra	5	-	-
T1-T12: neural arches	74	37	37
T1-T12: centra	13	-	-
L1-L5: neural arches	32	17	15
L1-L5: centra	20	-	-
S1-S5	20	10	10
Rib 1	4	2	2
Rib 2	4	2	2
Ribs 3-10	63	38	25
Rib 11	8	3	5
Rib 12	3	2	1
Ribs 1-12 (indeterminate side)	0	-	-
Scapula	1	0	1
Clavicle	2	1	1
Sternebrae	7	-	-
Humerus	5	2	3
Radius	4	2	2
Ulna	4	2	2
Ilium	5	2	3
Ischium	2	1	1
Pubis	3	1	2
Femur	6	3	3
Tibia	6	3	3
Fibula	2	1	1

Rhem: 7-10 years old

Element	**N**	**L**	**R**
Frontal	2	1	1
Parietal	2	1	1
Temporal	2	1	1
Occipital	0	0	0
Zygomatic	2	1	1
Maxilla	2	1	1
Nasal	0	0	0
Sphenoid	2	1	1
Mandible	2	1	1
C1	1	0	1
C2	1	1	1
C3-C6	3	3	3
C7	0	0	0
T1-T9	7	7	7
T10	1	1	1
T11	1	1	1
T12	1	1	1
L1-L5	4	4	4
Sacrum	1	1	1
Rib 1	0	0	0
Rib 2	0	0	0
Ribs 3-10	19	13	6
Rib 11	0	0	0
Rib 12	0	0	0
Ribs 1-12 (indeterminate side)	0	-	-
Scapula	2	1	1
Clavicle	2	1	1
Sternum	1	0	0
Humerus	1	1	0
Radius	2	1	1
Ulna	2	1	1
Ilium	2	1	1
Ischium	2	1	1
Pubis	2	1	1
Femur	2	1	1
Tibia	2	1	1
Fibula	2	1	1

Rhem: 11-18 years old

Element	**N**	**L**	**R**
Frontal	2	1	1
Parietal	2	1	1
Temporal	2	1	1
Occipital	2	1	1
Zygomatic	1	0	1
Maxilla	2	1	1
Sphenoid	0	0	0
Mandible	2	1	1
C1	0	0	0
C2	0	0	0
C3-C6	6	3	3
C7	2	1	1
T1-T9	16	8	8
T10	2	1	1
T11	2	1	1
T12	2	1	1
L1-L5	10	5	5
Sacrum (segments)	1	1	1
Rib 1	2	1	1
Rib 2	2	1	1
Ribs 3-10	15	8	7
Rib 11	1	1	0
Rib 12	1	1	0
Scapula	2	1	1
Clavicle	2	1	1
Sternum (Manubrium)	1	-	-
Humerus	2	1	1
Radius	2	1	1
Ulna	2	1	1
Carpals	*1	-	-
Metacarpals	6	-	-
Hand Phalanges	6	-	-
Ilium	2	1	1
Ischium	2	1	1
Pubis	2	1	1
Femur	2	1	1
Tibia	2	1	1
Fibula	2	1	1
Tarsals	4	0	4

Foscue: Preterm

Element	N	L	R
Frontal	0	0	0
Parietal	0	0	0
Temporal	1	0	1
Occipital (squamous)	0	0	0
Occipital (basilar)	0	0	0
Zygomatic	0	0	0
Maxilla	0	0	0
Nasal	0	0	0
Sphenoid	0	0	0
Mandible	0	0	0
C1	0	0	0
C2	0	0	0
C3-C7: Neural arches	0	0	0
C3-C7 centra	0	0	0
T1-T12: Neural arches	0	0	0
T1-T12 centra	0	0	0
L1-L5: Neural arches	0	0	0
L1-L5 centra	0	0	0
Sacrum	0	0	0
Rib 1	1	1	0
Rib 2	0	0	0
Ribs 3-10	6	2	4
Rib 11	0	0	0
Rib 12	0	0	0
Ribs (indeterminate side)	0	0	0
Scapula	0	0	0
Clavicle	2	1	1
Sternum	0	0	0
Humerus	3	1	2
Radius	4	2	2
Ulna	1	0	1
Ilium	1	0	1
Ischium	2	1	1
Pubis	0	0	0
Femur	6	3	3
Tibia	4	3	1
Fibula	0	0	0

Foscue: 3-6 years

Element	**N**	**L**	**R**
Frontal	2	1	1
Parietal	2	1	1
Temporal	2	1	1
Occipital (squamous)	2	1	1
Occipital (basilar)	2	1	1
Zygomatic	0	0	0
Maxilla	2	1	1
Nasal	2	1	1
Sphenoid	2	1	1
Mandible	0	0	0
C1	0	0	0
C2	0	0	0
C3-C7: Neural arches	0	0	0
C3-C7 centra	0	0	0
T1-T12: Neural arches	0	0	0
T1-T12 centra	0	0	0
L1-L5: Neural arches	0	0	0
L1-L5 centra	0	0	0
Sacrum	1	-	-
Rib 1	0	0	0
Rib 2	0	0	0
Ribs 3-10	0	0	0
Rib 11	0	0	0
Rib 12	0	0	0
Ribs (indeterminate side)	3	-	-
Scapula	0	0	0
Clavicle	0	0	0
Sternum	0	0	0
Humerus	0	0	1
Radius	0	0	1
Ulna	0	0	1
Ilium	1	0	1
Ischium	1	0	1
Pubis	1	0	1
Femur	1	0	1
Tibia	1	0	1
Fibula	1	0	1

APPENDIX B: SKELETAL MEASUREMENTS AND DIAGNOSTIC METHODS

Rhem: Birth-1 year

Method	Bone	Accession Number	Observation	Age estimation	Reference
Dental formation	Mandible	B.38	Lm$_2$= Cr3/4; Lm$_1$= Cr3/4; Li$_2$=Crc; Li$_1$=Crc; Ri$_2$=Crc; Ri$_1$=Crc; Rm$_2$= Cr3/4; Rm$_1$= Cr3/4	4-8 months	AlQahtani et al., 2010
Long bone length	Humerus	A.9a	75.0 mm	4.80 months (± 3.48 months)	Cardoso et al., 2014
		B.60e	75.13 mm	4.73 months (± 3.48 months)	
	Ulna	A.11	65.0 mm	4.38 months (± 3.0 months)	
	Radius	A.10	59.0 mm	5.12 months (±3.0 months)	
	Femur	F16.35u	100.14 mm	7.45 months (±2.76 months)	
	Tibia	B.65f	73.74 mm	3.61 months (±3.48 months)	
		B.71v	~84.0 mm	7.70 months (±3.48 months)	
Shoulder Girdle measurements	Scapula	B.53b	H: 44.05 mm B: 30.95 mm LoS: 37.12 mm BoG: 7.26 mm HoG: 16.32 mm	4-8 months	Cardoso et al. 2017

Pelvic Girdle measurements	Ilium	B.54c	L: 42.60 mm W: 45.61 mm	4-8 months	
	Pubis	B.56	L: 20.02 mm	4-8 months	
	Ischium	B.57	L: 25.57 mm W: 16.96 mm	4-8 months	

H, height; B, breadth; HoG, height of glenoid; BoG, breadth of glenoid; LoS, length of spine; L, length; W, width
Skeletal measurements are represented in millimeters (mm).

Rhem: 1-2 years

Method	Bone	Accession Number	Observation	Age estimation	Reference
Dental formation	Mandible	F.18.34	Lm_1=R1/2 Lc_1= Cr1/2	1.5 years (± 0.47 years)	AlQahtani et al., 2010
		D.40	Li_1= Cr1/2 LM_1=Cr3/4 RM_1=Cr3/4	1.5 years (± 0.47 years)	
		D.41	Lm_2= Crc Lm_1=R1/4 Lc_1= R1/2 Rc_1= R1/2 Rm_1= R1/4 Rm_2= Crc LM_1=Coc	1.5 years (± 0.47 years)	
	Maxilla	D.39	Rm^2=R1/4 Li^2=Cr1/2	1.5 years (± 0.47 years)	
Long bone length	Humerus	D.55q	101.00 mm	1.31 years (±0.29 years)	Cardoso et al., 2014
		D.56q	100.32 mm	1.29 years (±0.29 years)	
		F.16.32s	97.20 mm	1.18 years (±0.29 years)	
		B.69s	95.00 mm	1.10 years (±0.29 years)	

	Ulna	C.41	83.23 mm	1.23 years (±0.25 years)	
		F.18.40	90.05 mm	1.55 years (±0.25 years)	
	Radius	F.16.33t	75.73 mm	1.25 years (±0.25 years)	
		F.18.2x	74.10 mm	1.17 years (±0.25 years)	
	Femur	D.34h	~127.70 mm	1.26 years (±0.23 years)	
		F.18.44l	146.0 mm	1.71 years (±0.23 years)	
	Tibia	D.36	98.56 mm	1.12 years (±0.29 years)	
		F.17.1m	112.50 mm	1.59 years (±0.29 years)	
	Fibula	D.57	110.25 mm	1.60 years (±0.25 years)	
		F.16.37w	96.25 mm	1.18 years (±0.25 years)	
Shoulder Girdle Measurements	Clavicle	D.50p	59.14 mm	1.25 years (±0.31 years)	Cardoso et al., 2017
		F.16.31r	56.0 mm	1.01 years (±0.31 years)	
	Scapula	F.16.38	H: 49.47 mm B: 38.42 mm LoS: 43.65 mm BoG: 9.75 mm HoG: 19.02 mm	1-1.5 years	
		D.44n	H: 49.22 mm B: 39.97 mm LoS: 46.91 mm BoG: 9.39 mm HoG: 17.63 mm	1-1.5 years	

Pelvic Girdle Measurements	Pubis	D.52	L: 26.58 mm H: 18.30 mm	1-1.5 years	
		D.53	L: 32.38 mm H: 23.72 mm	1-1.5 years	
	Ischium	C.62.ss	L: 31.99 mm H: 20.58 mm	1-1.5 years	

Rhem: 3-6 years

Method	Bone	Accession Number	Observation	Age estimation	Reference
Dental formation	Mandible	C.73	Lm_1= Ac LI_1= R1/4 RI_1=R1/4	5.5 years (± 0.50 years)	AlQahtani et al., 2010
		D.104.a	Lm_2=Ac Lm_1=Ac Rm_2=Ac Rm_1=Ac LM_1=Crc RM_1=Crc	4-5 years (± 0.58 years)	
	Maxilla	D.104.b	Rm^2= Ac Rm^1=Ac		
		D.104.c	Rm^2= Ac Rm^1=Ac		
		F.15.1	Rm^2= Ac Rm^1= Ac Lm^1=Ac Lm^2=Ac LM^2=Crc	5.5 years (± 0.50 years)	
Long bone length	Humerus	D.145.mm	161.0 mm	5.63 years (± 1.31 years)	Cardoso et al., 2014
		D.98	~130.0 mm	~2.91 years (± 1.31 years)	
	Ulna	F.18.87.nn	130.0 mm	5.63 years (± 1.51 years)	
		F.17.5	~100.0 mm	~2.40 years (± 1.51 years)	
	Radius	C.45	95.0 mm	2.88 years (± 1.49 years)	
	Femur	D.99	176.0 mm	3.11 years (± 1.16 years)	

		F.16.113.aaa	181 mm	3.40 years (± 1.16 years)	
		F.18.95.pp	~206 mm	4.85 years (± 1.16 years)	
	Tibia	D.100	141.0 mm	3.04 years (± 1.35 years)	
		F.17.18.qq	179.0 mm	5.77 years (± 1.35 years)	
	Fibula	F.18.96	178.0 mm	5.90 years (± 1.36 years)	
Shoulder Girdle Measurements	Clavicle	F.15.64.z	78.0 mm	4.65 years (± 1.31 years)	Cardoso et al., 2017
Pelvic Girdle Measurements	Ilium	D.63	B: 71.91 mm H: 66.07 mm	2-3.5 years	
		D.98	B: 73.9 mm H: 69.03 mm	3-4 years	
		F.18.90	B: 84.50 mm H: 74.79 mm	5-6 years	
	Pubis	F.16.40	L: 34.0 mm H: 31.0 mm	2-3 years	
		F.18.92.oo	L: 39.69 mm H: 31.02 mm	4-5 years	
	Ischium	F.18.91.oo	L: 47.38 mm H: 34.34 mm	5-7 years	

Rhem: 7-10 years

Method	Bone	Accession Number	Observation	Age estimation	Reference
Dental formation	Mandible	D.113.jj	Lm_2=Ac Rm_2=Ac LM_2= Coc LM_1=Ac LI_2= R3/4 RI_2= R3/4 RC_1=Cr3/4 RM_1= Ac RM_2= Coc	7.5 years (± 0.49 years)	AlQahtani et al., 2010
	Maxilla	F.18.59.jj	Rm^2= Ac Lm^2= Ac RC^1=Cr1/2 LC^1=Crc LP^3=Cr3/4 LM^1=Ac LM^2=Crc	9.5 years (± 0.64 years)	
Long bone length	Humerus	D.166	193 mm	8.45 years (±1.31)	Cardoso et al., 2014
	Radius	D.167.w	140.0 mm	8.13 years (±1.49 years)	
	Femur	D.169.xx	265.0 mm	8.28 years (± 1.16 years)	
	Tibia	D.172.yy	216.0 mm	8.44 years (± 1.35 years)	
	Fibula	D.173.zz	212.0 mm	8.35 years (± 1.36 years)	
Shoulder Girdle Measurements	Scapula	D.162.tt	H: 85.24 mm B: 64.08 mm LoS: 79.70 mm BoG: 15.66 mm HoG: 23.06 mm	6-9 years	Cardoso et al., 2017
Pelvic Girdle Measurements	Pubis	D.176.aaa	L: 47.68 mm H:40.08 mm	7-8 years	
	Ischium	D.175.aaa	L: 61.15 mm H: 36.54 mm	7-8 years	

Rhem: 11-18 years

Method	Bone	Accession Number	Observation	Age estimation	Reference
Dental formation	Mandible	F.16.67	LP$_4$: R3/4 LP$_3$:A1/2 LC$_1$: A1/2 LI$_2$: Ac LI$_1$: Ac RI$_2$: Ac RC$_1$: A1/2 RP$_3$: A1/2 RP$_4$: R3/4	13.5 (± 1.17 years)	AlQahtani et al., 2010
	Maxilla	F.16.68	RP^4: Rc RP^3: A1/2 RC^1: Rc RI^2: Rc RI^1: Ac LI^1: Ac LI^2: Rc LC^1: Rc LP^3: Ac LM^3: Crc	13.5 (± 1.17 years)	
Long bone length	Radius	F.16.54	187.0 mm	13.62 years (±1.49 years)	Cardoso et al., 2014
	Femur	F.16.62	371.0 mm	14.43 years (±1.16 years)	
	Tibia	B.80	286.0 mm	13.49 years (±1.35 years)	
	Fibula	B.81	284.0 mm	13.53 years (±1.36 years)	
Shoulder girdle measurement	Clavicle	F.16.43	110.0 mm	11.77 years (±1.31 years)	Cardoso et al., 2017
	Scapula	F.16.47	LoS: 99.47 mm BoG: 19.01 mm HoG: 42.14 mm	12-13 years old	
Pelvic girdle measurement	Ilium	F.16.59	B: ~111.46 mm H: ~101.13 mm	11-12 years old	

APPENDIX C: MEASUREMENTS AND CALCULATIONS OF LINEAR ENAMEL HYPOPLASIAS

Rhem: Individual 5 (12.5-14.5 years old)

Tooth	**Number of LEHs**	**Distance from CEJ (mm)**	**Age of Occurrence (years)**
RC^1	2	3.49	3.82
		6.21	2.12
RI^2	1	2.14	3.64
RI^1	5	1.05	4.02
		1.96	3.61
		4.30	2.55
		6.59	1.51
		8.99	0.42
LI^1	7	1.41	3.86
		2.17	3.51
		3.25	3.02
		5.18	2.15
		6.70	1.46
		7.43	1.13
		9.12	0.36
LI^2	1	5.19	2.14
LC^1	1	3.37	3.89
LM$_1$	1	3.17	2.31
LP$_4$	1	2.64	5.31
LC$_1$	3	2.76	4.88
		4.20	4.03
		5.67	3.17
LI$_2$	3	2.52	2.95
		3.66	2.47
		5.26	1.81
LI$_1$	3	4.54	1.91
		5.82	1.32
		7.66	0.48
RI$_2$	4	3.42	2.57
		4.85	1.98
		6.33	1.36
		8.03	0.65
RC$_1$	3	3.00	4.74
		4.26	4.00
		5.61	3.20
		4.56	4.08

Rhem: Individual 6 (8-10 years old)

Tooth	**Number of LEHs**	**Distance from CEJ (mm)**	**Age of Occurrence (years)**
RC^1	2	5.83	2.36
		3.60	3.75
RI$_2$	2	2.40	3.00
		4.50	2.12