Growth as an Indicator of Social and Economic Transition from the Islamic to Late Medieval Christian Period in Portugal: a comparative study of linear and appositional growth

by

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Abstract

Objectives: This study explores whether child growth has signaled periods of social change between the Medieval Islamic and post-Islamic Christian Periods in Santarém, Portugal, employing evidence for indicators of stress to examine shifts in the social environment. One major social change came with the Golden Age of Islam, when social improvements may have led to better living conditions, through an improvement in the social determinates of health.

Materials and methods: Using 42 juvenile skeletons, age was calculated from tooth length. Linear growth of diaphyseal length for all long bones and appositional growth of the femur midshaft were compared with expected growth from the Denver Growth Study, using z-score.

Results: Meaningful long bone length stunting was found throughout the Medieval Islamic and Christian Periods in Santarém, as well as a deficit in appositional growth of cortical bone. There was more evidence for growth disruption in children aged two years or more. Although children in the post-Islamic Christian period showed a trend towards increased linear and appositional growth deficits, these differences were not statistically significant.

Discussion: Deficits were extensively observed throughout the neonate stage to older juveniles in both the Medieval Islamic and Late Medieval Christian Periods, causing growth disruption. These patterns of growth deficits were stronger for those aged two or more, which suggests that extrinsic sources of stress were causing accumulated deficits. Further studies are needed to explore the possibility that the Islamic Period was more favourable for child growth.

Keywords: growth and development; long bone growth; linear growth; cortical bone; appositional growth; Medieval; Portugal; social environment
Dedication

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Chapter 1.

Introduction

How social and physical environmental conditions have impacted growth and later outcomes of childhood health has long been the interest of the modern medical field (Godfrey & Barker, 2001; Lampl, Mummert, & Schoen, 2015; Marmot, 2005). Health studies have found that maternal health and nutrition influence fetal development, and that poor maternal health led to fetal outcomes such as low infant muscle mass and reduced bone mineralization (Bogin, Silva, & Rios, 2007; Lampl et al., 2015). This exposure to stress during fetal development can cause significant health issues in adult life (Godfrey & Barker, 2001). Juvenile development and childhood health determinates including nutrition, infection, abuse, psychological stress, and physical activity levels have also been found to cause growth faltering, stunting, motor and cognitive delays, reduced bone and muscle mass, and childhood mortality (Bogin et al., 2007). The World Health Organization recognizes how daily life, living conditions, and socio-political structure are the driving forces behind the social determinates of health (WHO Commission on Social Determinants of Health & World Health Organization, 2008). These social determinates of health in modern populations include nutrition, infectious diseases, access to clean water, access to medical care, early life conditions, socio-economic status, ethnicity, and migration (Cameron & Bogin, 2012; Ingleby, 2012; Marmot, 2005; WHO Commission on Social Determinants of Health & World Health Organization, 2008). Unsafe water due to sanitation is among the most vital, as dirty water is a disease vector for parasitic worms whose diseases have significant ramifications for growth and development (Neiderud, 2015). These extrinsic factors can have substantial impact on fetal and juvenile growth and development which is the basis for life-long health (Godfrey & Barker, 2001; Lampl et al., 2015; WHO Commission on Social Determinants of Health & World Health Organization, 2008).

Under this biocultural lens, we are able to apply foundations in biology, developmental psychology, endocrinology, and physical anthropology to explore the role of juvenile growth and development in population health studies (Bogin, 1995). The theoretical foundation for using juvenile growth data to explore aspects of population health is hinged on the understanding that growth is a controlled biological process. Growth and development are highly sensitive to interference caused by extrinsic stress, such as social determinates of health, comprising stress
factors that are dependent on a person’s social environment (Bogin, 1995; L. Schell, 1986; L. M. Schell, 1997; Tanner, 1963). As children are most responsive to extrinsic stress in the growing period, through their interactions with the social and physical environment, they are well suited for capturing the array of stress the entire population experiences (Lewis, 2007; Saunders, 2008). Growth disruption and/or delay is one of the many results of extrinsic stress on the body during the growth stage (Saunders, 2008). Understanding the crucial role that the social environment has on both growth and health outcomes, this perspective has been applied to the study of skeletal remains to address how past environments affected growth and development (Agarwal, 2016; Bogin, 1995; Cardoso, 2005; Cardoso & Garcia, 2009; Goodman & Armelagos, 1989; Harrington & Pfeiffer, 2008; Hoppa, 1992; Ives & Humphrey, 2017; Mays, 1999; Mays, Brickley, & Ives, 2008; Mays, Ives, & Brickley, 2009; Robles et al., 1991; Steckel, 2005). This complex relationship is illustrated in Figure 1.

![Diagram](image_url)

**Figure 1.** Social determinates of physiological stress, adapted from Fig. 1 in Goodman and Armelagos (1989).

The interaction of growth and the social determinates of health in the past falls under the umbrella of bioarchaeology (Agarwal, 2016). Juvenile growth and development is a proxy for population health and is an essential part of archaeology for understanding past lifeways (Cardoso, 2005; Lewis, 2007; Saunders, 2008). Nutrition, infection, and physical activity are the drivers for growth, which is moderated by genetic and extrinsic environmental factors (Cameron & Bogin, 2012; Cardoso, 2005). While biological determinates are important, we know that environmental factors are the driving force for growth variation between populations, which is why growth is used as a measure for environmental stress (Bogin, 1999). Linear growth is a biological process that is understood to be both affected by genetic and social factors; however because most growth deficits are environmentally driven and not genetic, standards of expected growth can be calculated which reflect healthy living conditions (Lewis, 2007). The use of a
growth standard, based on healthy children, provides researchers with the best opportunity to identify growth deficits (Onis, 2006).

Stress experienced during juvenile growth and development, such as malnutrition or disease, can result in the delay of skeletal growth. Delay of growth or stunting occurs as a biological function where growth is halted for energy to be used for more urgent needs (Cameron & Bogin, 2012). The degree of impact to growth and development can be used as a proxy to understand the severity of stress on the individual (Agarwal, 2016; Cardoso, 2005; Lewis, 2007). This process of responding to stress and resulting growth based on extrinsic environmental factors is the main reason for why growth and development studies are used as analogies for population health (Cardoso, 2005). Exposure to stress can be ongoing; the frailest children are the most susceptible to further stress through a weakened immune system, causing an accumulation of stress and limiting the effects of catch-up growth, and therefore increasing growth deficits over time (Cameron & Bogin, 2012; Tanner, 1963). Our project addresses concepts of growth and development in a new light by comparing two populations that experienced a significant social transition. Our work builds on a vast literature which explores many of the avenues of how the skeleton exhibits stress through: long bone growth disruption; appositional bone growth disruption; harris lines formation; enamel defect formation; periostitis; and mortality, caused by the social and physical environment including such determinates as nutrition, infectious diseases, mortality biases, socioeconomic status, and urbanization (Agarwal, 2016; Cardoso, 2005; Cardoso & Garcia, 2009; Goodman & Armelagos, 1989; Harrington & Pfeiffer, 2008; Hoppa, 1992; Ives & Humphrey, 2017; Mays, 1999; Mays et al., 2008, 2009; Robles et al., 1991; Saunders, 2008; Saunders & Hoppa, 1993).

Understanding the driving forces behind infant and juvenile mortality aids bioarchaeologists in their interpretations of their data. Foundations for successful juvenile growth and development are known to begin in utero as skeletal formation begins during the 12th week of gestation where both intramembranous and endochondral ossification occurs (Lewis, 2007). Therefore, maternal health is the first determinate that effects life, as the fetal growing period is the most impactful on development (Bogin et al., 2007; Godfrey & Barker, 2001; Lampl et al., 2015). Effects of poor maternal health, including malnutrition and disease, can result in low birth weight and being small for gestational age (Lewis, 2007). Being born small for gestational age has the known skeletal effect of radius and ulna stunting (Brooke, Wood, & Butters, 1984). After birth, the infant is still highly dependent on care but is no longer protected within the womb and is directly impacted by the physical environment (Hayward,
The infant developmental stage and the weaning period were high-risk intervals in childhood as extrinsic stress, especially malnutrition, had greater deleterious effect at these times (Goodman & Armelagos, 1989; Lewis, 2007). The high-risk nature of weaning and the first two years of life, is due to nutritional demand which is at the highest point for any period in life (Goodman & Armelagos, 1989; Saunders & Hoppa, 1993).

Various measures can be employed to examine changes in growth and development in archaeological populations. This study utilizes two: long bone linear growth, which is viewed as a mainstay in growth studies as there is a known nearly linear relationship to age (Mays et al., 2008), and appositional bone development, which is employed less frequently as a tool to examine growth (Ruff, Garofalo, & Holmes, 2013). However, a few early studies have analyzed cortical bone growth in children experiencing nutritional stress (Garn, Guzmán, & Wagner, 1969; Himes et al., 1975; Huss-Ashmore, 1981). Bone development can be separated into two parts: linear and appositional growth. Linear growth functions as a process of endochondral development where layers of bone replace cartilage at growth plates (Lewis, 2007; Mays, 1999). This process of chondroblast activity in tubular bones, including long bones, ceases when the epiphysis fuses to the diaphysis along this growth plate (Lewis, 2007). This method of using long bones as a proxy for stature or specific bone-by-age analysis allows bioarchaeologists to examine how stress impacted linear or statural growth in the past (Cardoso, 2005; S. Mays et al., 2008; Ruff et al., 2013), since long bone growth is known to be adversely effected by external stress (Cardoso, 2005; Ives & Humphrey, 2017; Vercellotti et al., 2014). Some proposed sources of extrinsic stress include, but are not limited to, the weaning process, sanitation, nutrition, and disease (Ives & Humphrey, 2017; Saunders, 2008). Appositional growth is often called ‘bone remodelling’ and is a lifelong process on the surface of all bones (Lewis, 2007). This skeletal development occurs when osteoblasts layer new bone on the periosteal surface of cortical bone and osteoclasts destroys bone on the endosteal surface (Lewis, 2007). In appositional growth in healthy children, the rate of new bone growth and destruction is fixed where bone is added to the periosteal surface and removed from the endosteal surface (Lewis, 2007; Mays, 1999). When stress impacts this fixed rate, it results in a skeletal indicator of this stress through atrophy of bone or thinning of cortical bone (Garn et al., 1969; Lewis, 2007; Mays et al., 2009). Cortical bone is found to be thinner in children experiencing stress from malnourishment or belonging to lower social classes (Garn et al., 1969; Huss-Ashmore, 1981; Mays et al., 2009; Ruff et al., 2013). The loss of cortical bone is most closely tied with increased resorption of cortical bone on the endosteal surface, rather than
decreased deposition (Garn et al., 1969; Mays et al., 2009). Atrophy, through the failure of deposition on the periosteal surface has also been found in children (Himes et al., 1975; Huss-Ashmore, 1981) and an increase loss of cortical bone on the endosteal surface has been found in adults (Garn et al., 1969). By examining the rate of bone remodeling, bioarchaeologists can use alternative means to assess how a population responded to stress (Mays et al., 2008, 2009; Ruff et al., 2013).

The way in which people experience and interact with their environment is highly impactful to their lives, beginning at the earliest stages of life. Social determinants of health contribute to the extrinsic social and physical environment which in turn effects living conditions, having a significant impact on population health. One of the best ways to address population health is through juvenile growth and development because childhood physiological development is highly dynamic and reflective of what the entire population experiences. We apply changes in both linear and appositional growth to examine how the changing social environment effected growth and development.

This study aims to address how a changing society can impact population health through an examination of juvenile growth and development during a transitional period of Portuguese Medieval history. By conducting the most extensive analysis of juvenile growth in Santarém to date, we seek to develop the first detailed examination of this transitional period from a bioarchaeological perspective. Very few studies have examined changes in growth and development in children during either the Medieval Islamic or Christian Periods (700-1600 AD) in the Iberian Peninsula by investigating aspects of stress (Cardoso & Garcia, 2009; Martín, 2000; Robles et al., 1991). Inskip (2016) states that beyond a few notable exceptions, bioarchaeological studies into the Islamic Period are typically limited to an overview of funerary practices. There is an under-representation of Islamic bioarchaeological investigations, likely due to social practice of not disturbing graves (Insoll, 1999). However, there are a significant number of archeological projects on Islamic Spain and Portugal focused on historical narratives, ceramics, and urban development (Boone & Benco, 1999; Boone & Worman, 2007; Bugalhão, 2009; Catarino, 1995; Chapoulie, Déléry, Daniel, & Vendrell-Saz, 2005; Curta, 2011; De Meulemeester, 2005; Inácio et al., 2015).

The introduction of Islamic society to the Iberian Peninsula in 711 AD (E. Moreno, 2010) brought a new way of life which fundamentally changed to the social and physical environment. These improvements included technological advances and new scholarly perspectives (Carvajal
López, 2016b; Freely, 2015; Gil’adi, 1992). Another major transition occurred later with the Christian conquest and the establishment of the Portuguese kingdom in 1143 AD (Disney, 2009). This shift in power changed the social environment once again, when a Christian feudal system was introduced (da Goia, 2011). Although there was a great movement of people during these times, we know that environmental factors impact growth much more than genetic variation (Bogin, 1999) and, therefore, we assume that any changes in growth observed were due to extrinsic stress, and not intrinsic variables. To date, no bioarchaeological project has examined the changing environment through a comparative growth and developmental study during the Medieval Islamic to Late Medieval Christian transition in one location. The present study of Santarém, Portugal provides this opportunity as it has a large skeletal repository and a well-established settlement throughout the Medieval Islamic and Christian periods.

Our assumption that the growth deficits seen in this study are caused by extrinsic stress, from the social and/or physical environment, and not genetic variation, is supported in the understanding that the majority of growth outcomes are due to environmental constraints (Bogin, 1999). Social determinates of health and the resulting extrinsic factors from the social environment can change with transitional societies. The transition from Medieval Islamic to Late Medieval Christian Portugal is well-suited for a comparative growth study because there was a known change in the social environment. Particularly there were differences in the social environment and extrinsic stress, including disease spread, hygiene, nutrition, and social attitudes towards children. Understanding both the environmental influences on linear and appositional growth, as well as the changes to society in Medieval Portugal, we expect to see improved growth of long bones and cortical bone development for children who lived during the Medieval Islamic Period, when compared to the Late Medieval Christian Period. Therefore, this project will serve as a driver to better understand the transition from the Medieval Islamic Period to Late Medieval Christian Period to further explore how this societal change and resulting extrinsic stress in Santarém may have adversely affected juvenile growth and development.
Chapter 2. Background

The introduction of Islamic people brought a new social environment through scholarly interests to Portugal and with this, attitudes towards children and changes to the physical environment by means of urbanization, agricultural diversity, and technological improvements (Carvajal López, 2016b; Freely, 2015; Gil’adi, 1992; Salas-Salvadó, Huetos-Solano, García-Lorda, & Bulló, 2006; Trindade, 2007). With its transition back to a Christian kingdom, Portugal once again underwent significant social changes, whereby medical treatment, urbanization, agricultural land use, and tolerance of minorities shifted (Birmingham, 2003; Martins, 2017; Soyer, 2007; Trindade, 2007).

Medieval Islamic Europe

The arrival of Islamic people from North Africa and the Middle East to the Iberian Peninsula began in 711 AD, and introduced an initial 50 to 60 thousand people; most of these new-comers were North African Berbers, with those from the Arab Peninsula constituting the higher social classes (da Goia, 2011; Freely, 2015). The name ascribed to the Iberian Peninsula while under Islamic control was Al-Andalus (Carvajal López, 2016a). The first capital of Al-Andalus was established in Córdoba, Spain, in 716 AD, and was ruled by the Umayyad Caliphate (Kennedy, 2004; Safran, 2013). Their power began to fail with the death of al-Hakam II in 976 AD and in less than a century the caliphate was abolished in 1031 AD (Viguera Molíns, 2010). The 11th century also brought the beginning of the Christian conquest and the reign of the Almoravids, who fought for re-Islamization of the Iberian Peninsula through their more orthodox perspective (Azevedo, 2013; Kennedy, 2004; Safran, 2013). The arrival of Christians from the North and the Almoravids in the south led to a cultural cleansing committed by both parties (Azevedo, 2013). The Christian conquest moved swiftly; by 1251 AD, Córdoba was captured, leaving Granada as the last city to be conquered in 1492 AD (Freely, 2015). Islamic presence in the Iberian Peninsula formally ended with the expulsion of Muslims from Portugal in 1496 AD (Soyer, 2007, 2008) and in Spain in 1609 AD (Scott, 1904).

Though cities had been previously settled prior to the Islamic occupation, urban growth during the Islamic Period resulted in dense living conditions where residential areas remained separate from other aspects of commercial urban life (Trindade, 2007). This was significantly modified after the Christian conquest; the intentional destruction or significant modification of
fortified or religious areas throughout served as a tool for Christian order and control and residential and commercial urban life was not separated (Trindade, 2007). This shift in urbanization would have impacted health outcomes as residential and commercial areas were no longer separate, introducing increased risk for disease vectors (de Hollander & Staatsen, 2003; Neiderud, 2015). We know that healthy living conditions in urban environments is dependent on clean water and sanitation through good waste management, rodent population control, and interactions with domestic animals (Neiderud, 2015).

While Portugal lacks large architectural reminders of this unique period in history, the Medieval Islamic Period in Portugal reflects an important time, often referred to as the *Golden Age of Islam* (da Goia, 2011; Freely, 2015; Salas-Salvadó et al., 2006). Islamic control of the Iberian Peninsula from the 8th to 11th centuries introduced a new way of life and is contributed to radical progress in a variety of fields, including agriculture, medicine, architecture, music, sciences, mathematics, astronomy, and physics (Carvajal López, 2016b; Freely, 2015; Lombard, 1975; Salas-Salvadó et al., 2006). This culturally and intellectually rich period in the Iberian Peninsula set Spain and Portugal apart from the rest of Europe (which was dealing with the repercussions of the collapse of the Roman Empire) (Lombard, 1975) and is thought to have helped spark the Renaissance, bringing Europe out of the Dark Ages (Levi, 2012; Salas-Salvadó et al., 2006). The influx of knowledge from Islamic scholars is also recognized as having given Portugal a key advantage during the Age of Exploration through Portugal’s application of cartography, ship building, and navigation (Levi, 2012). Al-Andalus was described as a place of religious tolerance (Novikoff, 2005) due to Islamic religious edicts protecting Christians and Jews as People of the Book (Safran, 2013). However, there are few historical records to confirm the rights and protections of religious minorities (Safran, 2013) and the concept of what defines ‘tolerance’ is debated (Novikoff, 2005). Other researchers disagree with this positive portrayal and dispute the idealized tolerance (Fernández-Morera, 2016; Novikoff, 2005) stating that Al-Andalus was responsible for destroying Visigoth culture and cutting off Europe from Christian Greco-Roman philosophies (Fernández-Morera, 2016).

Agriculture and diet changed significantly during the Islamic Period, when new crops and irrigation technologies were introduced (Carvajal López, 2016b). These agricultural improvements allowed for the cultivation of crops that otherwise would not be suitable for the climate of the Iberian Peninsula (Carvajal López, 2016b). Crops, such as olives, grapes, wheat, and barley, did not require artificial irrigation and were already intensively grown throughout Al-Andalus since the Roman Period (San José, 2005). New crops which required artificial irrigation
technologies were introduced to the region, including cotton, sugar cane, oranges, lemon, rice, eggplant, banana, spinach, melon, date palm, sorghum, durum wheat, coconut, mango, and mulberry (Alonso, Antolín, & Kirchner, 2014; San José, 2005). The diet of Al-Andalus was diverse, including cereal grains, starch purées, fruits, nuts, fish, and meat (Salas-Salvadó et al., 2006). Some foods were of higher social value, such as chicken and lamb, and the lower classes ate more fish and eggs (Salas-Salvadó et al., 2006). While pork was banned for consumption due to religious edicts, its nutritional value was appreciated by physicians at the time (Salas-Salvadó et al., 2006). Diet, nutrition, and caloric intake have a known positive correlation to attained growth (Gunnell et al., 1998). Therefore, the known diversified diet in Al-Andalus could be expected to have positively benefited growth and health.

In Al-Andalus there was significant interest in preserving Greek medical practices, such as the theories of natural causation and the four humors, as well as incorporating the role of Islam in treatment, where prayer was used to treat everyday maladies (Gallagher, 1993). Further adding to the distinction of Al-Andalus was the practice of funding hospitals through the collection of waqfs, or donations, which is one of the pillars of Islam (Gallagher, 1993; Insoll, 1999). Medical treatment was also highly scientific, with extensive writings of Islamic medical philosophies and the foundation of a physician’s school in Córdoba in the 10th century (Freely, 2015; Gallagher, 1993). This interest in medicine was not limited to Al-Andalus, but all of the Islamic world, which benefited through a network of sharing knowledge and people (Gallagher, 1993).

During the Medieval Islamic Period in Al-Andalus, the interest and academic pursuit of pediatric care is notable (Gil’adi, 1992). Distinguished figures include Al-Qayrawani, a pioneer in pediatric care whose writings discussed a variety of topics including hygiene, breastfeeding, and diseases; and Rhazes who developed experimental medicine as a field and approached medicine in three spheres, public health, preventative medicine, and treatment (Gil’adi, 1992; Salas-Salvadó et al., 2006). Important work to come from this period includes Rhazes’ record of the differences and treatment for smallpox and measles and an extensive 30-volume encyclopedia of all aspects of medicine by al-Zaharwi including patient care, anatomy, and hygiene (Dols, 1993; Freely, 2015). This interest in pediatric medicine did not spread to Western Europe until the 13th century (Gil’adi, 1992), but even then, some Islamic perspectives on medicine were not embraced (Martins, 2017), highlighting how the Iberian Peninsula experienced a vastly different way of health care in Al-Andalus. As hygiene and disease are social determinates of health, the attention given to these and other aspects of medical care
during the Medieval Islamic Period are expected to have improved living conditions during this time.

As previously discussed, child health was of interest in Al-Andalus. Although there was a high level of understanding and interest in pediatric care, this may not have directly affected the social environment and reduced extrinsic stress. There was a high death rate for infants and children under two, with higher death rates for those of lower socio-economic status, which seemingly was a universal trend in the medieval world (Gil’adi, 1992). Gil’adi (1992) argued that infant death in the Medieval world was often due to stress on maternal health through the constant demand of continuous pregnancies, complications during pregnancy and child birth, and the birth of twins. While the value of breast-feeding was understood, the mother could not always provide milk, and malnutrition and death were risks for infants and children during this time (Gil’adi, 1992). Boys were preferred over girls and infanticide, although banned under Islamic law, was practiced to control the births of disabled infants, unwanted girls, or illegitimate children (Gil’adi, 1992). Physical punishment for children was practiced but differed for boys and girls; this was mostly directed towards boys where cases of neglect, abandonment, and violence did occur (Gil’adi, 1992). In cases of early death where the infant had not cried, burial rites were not given at the grave site and these children were buried in a separate area of the cemetery (Petersen, 2013). For infant deaths, these children were also buried in separately (Petersen, 2013), but the funerary rites accorded to them, such as washing the body and prayers, were similar to those given to adults (Gil’adi, 1992).

How children fit within society and the social environment of Medieval Islamic Portugal would have dictated the stress they experienced. Treatment and care for children was important, as it was understood that this was a formative period and could have long-lasting effects on physical and psychological health (Gil’adi, 1992). Gil’adi (1992) provides a detailed examination of medieval Islamic children, and his findings address many topics including the treatment towards and development of children, which is explored in detail here. There was not one universal method for child-rearing; Gil’adi explains that individuality was appreciated and treatment was individualized. Childhood growth and development was viewed through lenses of physiological, psychological, and cultural development. Important milestones in childhood would have helped place children into society. A significant physiological stage of development was dental eruption, which could occur as early as five months or as late as ten months. Weaning after two years was recommended by Islamic doctors and the Quran. Important infant socio-cultural developments included first prayers and naming, when an infant became an individual.
The age of seven, moreover, was an important stage for Medieval Islamic children, at which time boys and girls were viewed as different, made evident through outward appearances and treatment (Gil’adi, 1992; Hirsch, 2014). At this stage, boys were transitioned into adult society, whereas for girls, this was delayed until the age of nine due to the onset of puberty (Gil’adi, 1992). Under Islamic law, the removal of maternal custody for boys occurred with puberty, and marriage for girls (Gil’adi, 1992). Childhood ended at the age of fifteen or evidence of physical maturity (Hirsch, 2014).

The Christian conquest and Late Medieval Christian Period

The Christian conquest of Spain and Portugal has long been viewed as liberating the Iberian Peninsula through a holy war. This perspective has been shifting over time in academic spheres to properly acknowledge the significance and influence of Al-Andalus (da Goia, 2011). The Christian conquest began in second half the 11\textsuperscript{th} century, when Christian forces moved south. In 1125 AD, Alfonso I of Aragon partook in a 15-month long journey through Al-Andalus, which led to the resettling of Christians living under Islamic control to Aragon. This was a major upset to Islamic rulers, who subsequently expelled Christians from Granada, Cordoba, and Seville in 1126 AD (Viguera Molins, 2010). Lisbon was captured in 1147 AD, after a previously failed attempt in 1142 AD (Villegas-Aristizábal, 2013). The first kingdom of Portugal was established by Afonso Henriques in 1143 AD (Disney, 2009), and what would become Portugal was completely under Christian control in 1249 AD with the capture of Faro (Soyer, 2007). Under this kingdom, the people of Portugal were governed through an amalgamation of Roman, canonical, and Castilian laws (Azevedo, 2013).

Major changes to the social environment, through socio-economic status change, disease spread, malnutrition, migration, and treatment of ethnic minorities, would have been detrimental to population health. Portugal suffered greatly from the Christian conquest due to significant economic stress, famine, and disease (Birmingham, 2003). With the great movement of people, some regions became depopulated and the once productive agricultural lands were wasted (Birmingham, 2003). The kingdom suffered through the 14\textsuperscript{th}-century plague and significant political unrest, then later, Medieval Portugal transitioned into the Modern Period in 1640 AD with a revolution and an independence war with Spain (Birmingham, 2003).

After Portugal’s conquest, Muslims were free to live in taxed and segregated communities called \textit{mourarias} prior to their deportation out of Portugal in 1497 AD (Azevedo,
2013; Soyer, 2008; Trindade, 2007). However, not all Muslims lived free; the sale and forced labour of Muslim slaves occurred throughout the country, including in 1147 AD after the fall of Lisbon where Muslim prisoners were sold (Birmingham, 2003; Soyer, 2007). While the treatment of Muslims during the Christian conquest and following centuries was terrible, it is often overshadowed by the brutal treatment of Jews, which Soyer (2008) attributes to the lack of Muslim texts detailing their own treatment during this time.

Key aspects of population health are the social determinates of health, where medical treatment through disease control and hygiene is vital. Hospitals in the kingdom of Portugal were not places intended for treatment, but rather a place for the impoverished to live and to die (Conde, 1999). Hospitals were either funded by private donations or by religious institutions, and actual medical treatment was often received in the home (Conde, 1999; Martins, 2017). This network of hospitals and institutions of care were part of the Misericórdias system (Conde, 1999; Sá, 1995). Medical treatment and scholarly interest were not practiced in the same way as in the Islamic Period, medieval medical education suggested that urine analysis, prayer, astrological signs, bleeding, and pharmaceuticals were all valid methods for assessment and treatment (Martins, 2017). The impacts of Greco-Roman and Islamic medical scholars were largely lost on Late Medieval Christian Portugal, as medical training was conducted through lecturing, and hands-on experience in the practice of medicine was non-existent (Martins, 2017). The lack of medical care in hospitals is made evident by the estimated death rate of 43% of patients in the first ten days of hospitalization and 70% in the first month (Conde, 1999). This high death rate did not improve as Europe transitioned into the Modern Period, as elsewhere in Europe, children abandoned at institutions had, at best, a 50% survival rate (Vitale, 2014).

Some attitudes towards children were similar to those of Medieval Islam, however, burial treatment differed. Due to authority of the Pope, Medieval Catholicism was uniform in nature throughout Europe when dealing with concepts of treatment towards the dead (O'Sullivan, 2013). Infant health was precarious during the Late Medieval Christian Period, evidenced by the need for baptism to occur early in life to protect the soul in death (Oliveira, 2007). This was a shift from seasonal baptisms (Hausmair, 2017). The social need for baptism in the face of death was so great, that if need be, an infant could be baptised by a layperson, such as the midwife (Hausmair, 2017; Oliveira, 2007). In cases where baptism did not occur, children could not be buried in consecrated ground (Hausmair, 2017). Baptised deceased infants and children would have belonged to the theological place of either Heaven or Paradise, which would have dictated their burial indoors in close relation to the church altar (Hausmair, 2017). Those buried in
consecrated ground, but outside of the church were thought to be in Purgatory (Hausmair, 2017). Burial within the church was also preferred in Medieval Portugal (Queiroz & Rugg, 2003). Infanticide was also practiced in the Late Medieval Christian Period, although it was condemned (Sá, 1994). Abandonment was encouraged during the Medieval Period as a social measure to reduce infanticide rates (Silveira, 2009). To accommodate these abandoned children, hospitals or institutions for orphans were introduced, under the _misericórdias_ network (Sá, 1995; Silveira, 2009). In the beginning of the Modern Period, child abandonment was legalized to further reduce rates of infanticide. (Silveira, 2009). Like in the Islamic Period, there were important milestones that impacted the role, health, and treatment of children. An important social and physiological stage for children was the eruption of teeth, which marked the end of the infancy stage (Oliveira, 2006). Weaning was also done at age two for most of the Medieval world (Gilʿadi, 1992). Children were transitioned into adult society at age 12 for girls and 14 for boys (Oliveira, 2006; Silveira, 2009).

**Medieval Santarém**

Santarém, Portugal was first occupied in the 7th century BC (Conde, 1999). This area was well-suited for settlement because it took advantage of ecologically-diverse river systems, agricultural lands, and protective natural ramparts as a hilltop town (Anderson, 2000). During Roman times, Santarém had a military garrison and was a place of urban growth because of its ideal location, despite other regions falling into decline due to a crisis in the Roman empire (Conde, 1999); Santarém came under Visigoth rule in the 5th century AD (Birmingham, 2003). Santarém was under Visigoth rule for three centuries before becoming part of Al-Andalus in al-Garb, the west (Conde, 1999). Islamic rule came to Santarém with the conquest by Abd al-Aziz in 714 AD and was the center of the region (Conde, 1999; Custódio, Mata, & Nazaré, 1996; da Goia, 2011). Although it was on the western fringe of Al-Andalus, Santarém was still an important urban centre and remained semi-autonomous, on account of its location and resource wealth, while still following Islamic administrative practices (Conde, 1999; Custódio et al., 1996). Santarém saw several transitions of power during the Islamic Period; the Umayyad caliphate from 714 to 756 AD, the Abbasid caliphate until 929 AD, and the Taifa of Badajoz until 1031 AD (Baker, 1986; Custódio et al., 1996). After the collapse of the caliphate system, the Taifa of Badajoz still maintained control until 1093 AD, at which time the Christian conquest reached Santarém and Alfonso VI of Leon briefly took power of the city, who gave Santarém to the King of Jativa (Baker, 1986; Custódio et al., 1996). Skirmishes saw power transfer back to the
Almoravids in 1111 AD and finally back under Christian control in 1147 AD under Afonso Henriques of Portugal (Baker, 1986; Custódio et al., 1996).

Santarém was positioned along both river and land travel routes, and was well-situated for access to the Atlantic, having deep enough waters for larger boats to access its port from Lisbon (Conde, 1999). Despite its distant location in al-Garb from the centralized powers in Cordoba, Santarém still garnered the attention of Islamic scholars, who wrote of the bounty and economic value of the Tagus river. Conde (1999) summarizes how their writing included such comments as the flood plain being similar to the Nile, fields not requiring a fallow period, and the variety of foods that could be cultivated. These historical remarks make clear the resources that were readily at hand for people living in Santarém. Scholarly writing about the city, specifically is lacking, and therefore such knowledge as the location of the mosque is unknown. While detailed understanding of urban development is not attainable, it is understood that during the Islamic Period Santarém had increased urbanization along the river, and the hilltop fortress was 4 hectares in size (Conde, 1999). The entire city was around 20 hectares, with the centre of Santarém accounting for half of this area. This 10-hectare centre would have housed 3,500 people who were Muslim, Christian, and Jewish (Conde, 1999).

The skeletal remains analyzed in this study were excavated in the city of Santarém, Portugal beginning in 2003 and are curated by the Municipal Museum. The sample represents juvenile remains that date to either the Medieval Islamic Period (714-1147 AD) or the Late Medieval Christian Period (1147-1640 AD). This broad expanse of time of just under 1,000 years saw major social change with the introduction of a new religion and cultural group. There was also physical environmental change, as the Medieval Climate Anomaly of 900-1300 AD left Santarém in warm and dry conditions before cooling in the Little Ice Age (Moreno et al., 2012). These changes and transitions in the social and physical environments could have introduced or removed extrinsic stress, and these large societal changes are what we aim to address in this study.
Chapter 3. MATERIALS AND METHODS

The samples

This study utilises remains excavated from five cemeteries in the city of Santarém and is the most exhaustive survey of these periods to date conducted in this area. These sites all date to either the Medieval Islamic or Late Medieval Christian Periods and represent a short but dynamic part of Santarém’s occupation history (Custódio et al., 1996). The sites are named after the street or religious building from which they were excavated and include: Rua Cinco de Outubro; Rua Capelo e Ivens; Largo Cândido dos Reis; Convento de São Domingos; and Largo da Igreja de Santa Iria. Archaeological sites include both the plateau and river-front areas of Santarém (see Figure 2). The excavations of these cemeteries are dictated by the city’s protocols for salvage archaeology, where city development guides the excavation. Only the exact boundaries and depths of disturbed areas are excavated, and therefore all of these sites represent partially excavated cemeteries. Preservation varied between sites, therefore not all variables were collected from each individual.
Figure 2  Map of Santarém. Sites are shaded in blue and numbered. Site 1 is Convento de São Domingos, Site 2 is Largo Cândido dos Reis, Site 3 is Rua Capelo e Ivens, Site 4 is Rua Cinco de Outubro, and Site 5 is Largo de Santa Iria. Red areas are the known locations of the medieval city walls.
All individuals with unfused long bone epiphyses, at least one intact long bone, and at least one recognizable incompletely formed tooth were included in this study (n=42). We collected measurements from all six long bones for growth data as well as all dentition for age estimation. The sites that date to the Medieval Islamic Period include Rua Cinco de Outubro, Rua Capelo e Ivens, Largo Cândido dos Reis (see Table 1 for sample distribution). The sites that date to the Late Medieval Christian Period include Largo Cândido dos Reis, Convento de São Domingos, and Largo da Igreja de Santa Iria (see Table 1). Within both the Medieval Islamic and Christian Periods an Early or Late classification was made, inferences were made based on the urban growth of Santarém and historical records. The earliest site included (Rua Cinco de Outubro) yielded the highest contribution to the study as it was in a good state of preservation, forming the Early Islamic portion of this study. The Late Islamic Period consists of individuals from two nearby excavations, Rua Capelo e Ivens and Largo Cândido dos Reis. These sites are in very close proximity and have no distinct differences to separate them temporally. The Islamic context of these sites is consistent with how the city developed; as Santarém grew; cemeteries needed to be moved further northwest to remain outside of the area reserved for the living (Insoll, 1999; Liberato, 2012). The Early Christian sample only comes from Largo Cândido dos Reis, as it was known to have been used soon after Santarém was conquered (Custódio et al., 1996). The two Late Christian sites, Convento de São Domingos and Largo da Igreja de Santa Iria, had small sample sizes and poor preservation and were, therefore, combined to form the last phase of study as they were contemporary. We know that both sites would have followed later in the Late Medieval Christian Period, compared to Largo Cândido dos Reis, as they are located much further from the city center and Convento de São Domingos was outside the medieval walls. Furthermore, the date of cemetery use would have been later than the date of church construction or initial use.
Table 1. Sample size distribution by context, age, and skeletal elements.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Time Period</th>
<th>Historical Context</th>
<th>n</th>
<th>Age &lt;2</th>
<th>Age ≥2</th>
<th>Humerus</th>
<th>Radius</th>
<th>Ulna</th>
<th>Femur</th>
<th>Femur Midshaft</th>
<th>Tibia</th>
<th>Fibula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rua Cinco de Outubro</td>
<td>Medieval Islamic</td>
<td>Early</td>
<td>15</td>
<td>8</td>
<td>7</td>
<td>11</td>
<td>13</td>
<td>13</td>
<td>10</td>
<td>9</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Rua Capelo e Ivens</td>
<td>Medieval Islamic</td>
<td>Late</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td>9</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Largo Cândido dos Reis</td>
<td>Medieval Islamic</td>
<td>Late</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
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<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Largo Cândido dos Reis</td>
<td>Late Medieval Christian</td>
<td>Early</td>
<td>7</td>
<td>1</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Convento de São Domingos</td>
<td>Late Medieval Christian</td>
<td>Late</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
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<td>3</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Largo da Igreja de Santa Iria</td>
<td>Late Medieval Christian</td>
<td>Late</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Islamic Total:</td>
<td>Medieval Islamic</td>
<td></td>
<td>27</td>
<td>17</td>
<td>10</td>
<td>22</td>
<td>19</td>
<td>20</td>
<td>17</td>
<td>15</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>Christian Total:</td>
<td>Late Medieval Christian</td>
<td></td>
<td>15</td>
<td>2</td>
<td>13</td>
<td>12</td>
<td>11</td>
<td>9</td>
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<tr>
<td>Total:</td>
<td></td>
<td></td>
<td>42</td>
<td>19</td>
<td>23</td>
<td>34</td>
<td>30</td>
<td>29</td>
<td>25</td>
<td>22</td>
<td>27</td>
<td>13</td>
</tr>
</tbody>
</table>
Rua Cinco de Outubro is the earliest site included in this study and was excavated in two phases, from August to November 2007 and then later from June to September 2008 (Liberato 2012). From this site, all long bones are represented and contributed largely to the appositional bone growth analysis (see Table 1). The age distribution was fairly even (see Table 1). This cemetery was first used in Roman times and was utilized in the Islamic Period, until sometime during a period of urban development in the Medieval Islamic Period (Liberato, 2012). The cemetery fell into disuse as the city grew, due to religious edicts dictating that cemeteries be located beyond the city limits, outside the realm of the living (Insoll, 1999; Liberato, 2012). The Islamic burials were identified through burial context, as they were all buried on the right side with no associated grave goods, but not all were correctly oriented towards Mecca (Liberato, 2012). Some of the Islamic burials were positioned in the canonical style of northeast-southwest, although the heads were turned to face Mecca and others were positioned northeast-southwest, thus correctly positioned towards Mecca (Liberato, 2012). This shift in burial practices was likely due to the fact that this site represented a transitionary population where a pre-existing church could have been converted into a mosque and burials were oriented towards this structure (Liberato, 2012; E. Moreno, 2010), as they would have been some of Santarém’s first Islamic citizens. The varying positioning of graves also reflects how *quibla*, the direction towards Mecca, is determined by the sun’s position and can change seasonally (Petersen, 2013).

Rua Capelo e Ivens is believed to have been an Medieval Islamic site based on burial context and was excavated in 2013. From this sample five long bones are represented and five individuals are incorporated in the appositional bone growth analysis (see Table 1). This was a salvage excavation as the construction of foundation walls uncovered these burials, which mostly consisted of infants under the age of 6 months (n=6). The movement of cemeteries outwards from the city center is evident in the location of this site, just inside the medieval city walls (See Figure 2).

Largo Cândido dos Reis is the largest medieval cemetery excavated in Santarém. Excavations spanned over a year from 2004-2005, with 639 internments recovered. The sample size in this study was diminished by poor preservation in the area, which is attributed to both the acidic limestone soil and heavy tree root activity, which disturbed the soil and further increased the acidity (Matias, 2009b). Furthermore, this site lies under one of the major roadways in the plateau. This site represents a cemetery that was used in both the Medieval Islamic and Late Medieval Christian Periods (see Table 1) (Matias, 2009b, 2009a). Burials in the Islamic style of
being in contact with the ground was strictly followed here, as was the practice of individuals placed on their right sides, with the head positioned southwest, orienting the body southeast towards Mecca (Insoll, 1999; Matias, 2009b, 2009a; Petersen, 2013). During the 12th century, the cemetery fell into disuse, but was utilized once again in the 13th century during the Late Medieval Christian Period, under the care of the Ermida de Santa Maria Madalena and later Convento das Donas de São Domingos (Custódio et al., 1996; Matias, 2009b, 2009a). The new urban development of the Convento de Nossa Senhora do Sítio da Ordem Terceira de São Francisco led to the destruction of the Ermida in the 17th century and the complete disuse of the site (Custódio et al., 1996; Matias, 2009b, 2009a). The Christian burials were found outside of the religious building; the majority of which were in a dorsal position and followed the canonized west-east orientation (Matias, 2009a, 2009b).

Religious orders in Santarém intensified their role in the city as the Late Medieval Christian Period continued, moving further and further from the city center and the limits of the fortified area (Matias, 2009b). Convento de São Domingos is the furthest from the city center for hill-top sites and outside the city walls (see Figure 2). It was excavated as a salvage project by the Santarém municipal archaeology branch in the summer of 2008 and represents part of the Late Medieval Christian Period (see Table 1). The cemetery uncovered was positioned outside and closely associated with a convent for the Dominican Order that was built in the 13th century and was closed through a process of ecclesiastical reforms in the Modern Period. (Arquivo Nacional, 2017; Centro Nacional de Cultura, 2017; Custódio et al., 1996).

Largo da Igreja de Santa Iria was a salvage excavation that took place from September to November 2003 with further work until February 2004. This cemetery was outside of the church and was associated with the Late Medieval Christian Igreja de Santa Iria, beginning in the 13th century; however, the site was first used by the Visigoths in 653 AD (Custódio et al., 1996; Lopes dos Santos, 2004). At the beginning of the 13th century, two parishes on the river-front of Santarém combined to form a new congregation at Santa Iria (Custódio et al., 1996), representing the beginning of the Late Medieval Christian use of the site (see Table 1). The interments were found buried in a west-east orientation, in the dorsal position (Lopes dos Santos, 2004).
Methods

The maximum diaphyseal length of all six long bones were collected with a sliding digital caliper to the nearest tenth of a millimeter to assess for attained growth. Because sex is not distinguishable in juvenile remains (Saunders, 2008), no attempt to identify biological sex in the sample was made and reference data from both girls and boys were combined. If the bone was longer than 200 mm, an osteometric board was used to measure to the nearest millimeter. Maximum lengths were recorded from the left side, unless damaged, in which case bones from the right side were used. The methodology for long bone measurements follows the standards put forward by Buikstra and Ubelaker (1994). All measurements were collected by myself, except a small number of individuals had measurements taken by Hugo Cardoso or during the excavation process collected by António Matias.

To assess for variation in appositional bone growth, measurements from the femur midshaft were collected using digital radiographs. Data was collected using a portable digital radiograph machine. Radiographs were taken of both the anteroposterior and mediolateral planes based on protocols established by O’Neill and Ruff (2004), with the orientation to capture the true cross section, since the femur is not elliptical (O’Neill & Ruff, 2004). From these two radiographs the measurements of total width, medullary width, and cortical widths were collected (O’Neill & Ruff, 2004). These measurements were taken at the 50th percentile of the femur midshaft, found by using sliding digital calipers to measure from the distal end (O’Neill & Ruff, 2004), and marked with the placement of a 10 mm radio-opaque scale bar. ImageJ software was used to measure the midshaft and scale bar. The measurements were used to calculate total area, cortical area, cortical thickness, and medullary area (Mays, 2000; Ohman, 1993). Based on these calculations, cortical bone development and appositional growth could be ascertained.

Tooth length was used as a measure of age based on the methodology proposed by Liversidge, Dean, and Molleson (1993) for deciduous teeth and Liversidge and Molleson (1999) for permanent dentition. If dentition was loose, then a sliding digital caliper was used to take the total length to the nearest 10th of a millimeter. If a tooth could not be removed from the crypt, then a scaled radiograph was taken with a portable digital radiograph machine. The tooth was later measured using ImageJ software. This process was the same for either deciduous or permanent dentition; previous studies have shown that there are no meaningful differences between radiographically derived measurements and physical measurements (Cardoso, 2007,
Special attention was given to excessive tooth wear, root absorption, or completed apex closure. Only unworn teeth with incompletely formed crowns or roots were measured. The measurement for each available individual tooth was then converted to a tooth specific age according to formulae specific to dentition type (Liversidge et al., 1993; Liversidge & Molleson, 1999); these individual tooth ages were then averaged to obtain an age estimate for each individual. These averages are considered more precise estimates of age when combining values obtained from different teeth (Cardoso, 2007, 2009). The sample was truncated at the age of 12, as fusion of epiphyses to the diaphysis begins at about this age (Lewis, 2007).

Using linear measurements and dental ages, long bone length for age plots were constructed for each long bone. To examine the amount of growth deficits for age in the sample, the attained growth z-score for each individual from the sample was calculated using a modern healthy reference sample, from the longitudinal Denver Growth Study (Maresh, 1970). The Denver Growth Study sample is widely used as reference data for archaeological growth studies (Cardoso, 2005; Cardoso & Garcia, 2009; Harrington & Pfeiffer, 2008; Humphrey, 2003; Ives & Humphrey, 2017; Saunders, Hoppa, & Southern, 1993) because unlike other studies, this is the only study which includes expected growth for all six long bones and cortical bone and therefore is the only suitable reference data for this research. As the Denver Growth Study examined growth from a middle to upper-middle European descent population, this would have captured a population which lived under favourable conditions, namely quality and quantity of nutrition, reduced disease load, and access to medical care, reflecting a distribution of normal and healthy juvenile growth (Cardoso, 2005). A study by Saunders, Hoppa, and Southern (1993) found that their archaeological sample from a 19th century Canadian cemetery closely modeled the growth profiles from the Denver Growth Study. This bioarchaeological investigation supports the use of the Denver Growth Study in this analysis as reference data because the Saunders and colleagues project shows that archaeological populations can model modern growth expectations, based on the Denver Growth Study. This indicates that results based on the Denver Growth Study are not inherently biased towards growth deficits for past populations. To calculate the z-score, the combined means and standard deviations for both male and female individuals were used, employing the corrected measurements for radiograph distortion (Cardoso, 2005); individual z-scores were calculated by subtracting this combined mean and dividing by the combined standard deviation. The Denver Growth study data is presented with means and standard deviations for each age group and sex. For individuals under one year,
data was collected more frequently, at 0.17 years, 0.33 years, and 0.5 years, before switching to half year intervals (Cardoso, 2005). This allowed for z-scores to be calculated based on the dental age estimate and the applicable mean and standard deviation from the Denver Growth Study.

For a meaningful understanding of how appositional growth changed within the sample, the four calculations of total area, cortical area, cortical thickness, and medullary area were used. However, unlike long bone growth, there is no published data set to compare femur appositional growth to a longitudinal growth study. The original femur radiographs from the Denver Growth Study are preserved and can be used to extract expected development by age at the 50th percentile of the femur midshaft. Access to previously unpublished cortical bone data collected from the Denver Growth Study allowed for the calculation of means and standard deviations for each age group. Age groups were assigned based on the original Denver Growth Study, where a child was assigned the age group closest to their actual age. This approach provides data for expected development of appositional growth for a normal, healthy population, similar to linear growth. Having reference data for comparison allowed for a meaningful assessment of expected cortical bone development by age, to observed appositional growth from Santarém. Similar to the methods for linear growth, z-scores were computed based on the four cortical bone calculations and dental age, as well as the calculated means and standard deviations. This allowed for an intra- and inter-sample study.

The statistical tests applied in this project are intended to assess for any differences in growth both within the sample and between the sample and Denver Growth Study. These tests use 10 variables from this study; six linear measurements of humerus, ulna, radius, femur, tibia, and fibula lengths and four appositional measurements of total area, cortical area, cortical thickness, and medullary area. All variables were treated the same, in which, z-score were calculated for all variables and the same statistical tests were applied using SPSS. Scatterplots were created for each of the 10 variables to compare the expected growth trajectory in the study sample with the Denver Growth Study. Next, z-scores were calculated using the Denver Growth Study mean and standard deviation for the corresponding dental age. As reflected in Table 1, the age distribution in this sample is not evenly represented; there is limited overlap in ages and missing age ranges between sites and time periods. To account for this unequal representation and potential for biases due to age, z-score were used to standardize results. By using z-scores based on the Denver Growth Study, growth deficits are numerically represented by the distance from the mean for each age category. By calculating individual z-scores for small age groups,
any difference in size due to age was removed, and the rate of growth attainment could be compared sample-wide. A negative z-score would reflect an individual that did not reach the mean of expected growth and experienced a growth deficit. Individual z-scores were then compiled to find the mean z-score for each variable. Statistical tests would indicate if the degree of growth change, either a deficit or increase, as reflected in a negative or positive z-score was significant.

The calculated z-scores for the 10 variables were used for a statistical comparison of the difference between the reference sample and study sample, using a one sample t-test comparing the mean to zero. Due to sample size, to compare differences between the Islamic and Christian samples, the Kurskal-Wallis test was used to examine whether changes in linear and appositional growth variable means through time were statistically significant. Mean z-scores for all 10 variables, both linear and appositional growth were compared across groups in small time-scales (Early Islamic, Late Islamic, Early Christian, or Late Christian). These comparisons were tested using the total sample for each group and were separated by age category: individuals under two years of age (<2 years) or those two years of age or more (≥2 years), to reflect changes in growth velocity during development. Z-score means of the two age groups were compared using the Mann-Whitney test to examine whether changes in linear and appositional growth by age was statistically significant, as accumulation of stress through time is known to impact growth (Cameron & Bogin, 2012; Tanner, 1963).
Chapter 4. RESULTS

Linear Growth

Humerus.

Out of a total sample of 42 individuals, the humerus was the most frequent bone to be found in conditions suitable for this study (n=34). Using the humerus diaphyseal lengths, we were able to analyze the most representative sample to explore variation in growth. Growth in the length of the humerus is compared to the Denver Growth study, illustrated in Figure 3. The one sample t-test showed that the mean of the humerus z-score ($\bar{x}=-1.57$) for the total sample was statistically different from zero ($t=-4.536$, $p=0.000$). When examined by age category (see Table 2), we see growth deficits lessen through time. This trend is applicable to individuals less than two years of age and for individuals two years of age and older, however, these trends of z-score means were not statically significant (see Table 2). Compared to younger individuals, older individuals show greater levels of growth stunting. When examining the results by time period, the z-score means showed no statistically significant differences over time. The Mann-Whitney tests found that for the total sample, there was a statistically significant difference between z-score means (see Table 2) for those under the age of two and those two years old and greater ($Z=-2.036$, $p=0.042$). This shows that older individuals experienced increased growth deficits.
Figure 3  Scatterplot of humerus length against age of Medieval Islamic children (circle) and Late Medieval Christian children (square), compared to the Denver Growth study mean (solid line), one standard deviation (short dash), and two standard deviations (long dash).
Table 2  Sample size (n), mean (\( \bar{x} \)), and standard deviation (SD) for humerus diaphyseal length z-scores, broken down by time period and by age (below age two and at age two and above). Kruskal-Wallis test compared Early Islamic, Late Islamic, Early Christian, and Late Christian periods.

<table>
<thead>
<tr>
<th>Humerus Diaphyseal Length Z-Score</th>
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<th>Islamic Total</th>
<th>Early Islamic</th>
<th>Late Islamic</th>
<th>Christian Total</th>
<th>Early Christian</th>
<th>Late Christian</th>
<th>Kruskal-Wallis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>x</td>
<td>SD</td>
<td>n</td>
<td>x</td>
<td>SD</td>
<td>n</td>
<td>x</td>
</tr>
<tr>
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<td>22</td>
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<td>1.83</td>
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<td>-2.11</td>
</tr>
<tr>
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<td>-1.14</td>
<td>1.75</td>
<td>8</td>
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</tr>
<tr>
<td>Age ≥2</td>
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<td>2.00</td>
<td>6</td>
<td>-3.21</td>
<td>2.14</td>
<td>3</td>
<td>-3.32</td>
</tr>
</tbody>
</table>
Radius.

Overall, the z-score mean shows that radial growth and development was stunted (\(\bar{x}=-2.00\)) based on reference data and was found to be statically different from zero using a one sample t-test (\(t=-6.189, p=0.000\)). Figure 4 illustrates the attained growth in comparison to the expected reference values from the Denver study. If analyzing the results by all ages for each time period, we see a greater growth deficit through time (see Table 3). If we examined the z-score results by both small-time scale (Early Islamic, Late Islamic, Early Christian, and Late Christian) and by age category (under two years, or two years and older), there is a decrease in growth deficits through time. In both age groups (under two and two years and older), there is a decrease in growth deficits through time (see Table 3). The trends of increased or decreased growth deficits over time are present, however, these was not a significant result, based on the Kruskal-Wallis tests. The difference between age category z-score means (see Table 3) was also found to be statistically different (\(Z=-2.825, p=0.004\)). This shows that individuals two years old or more have greater growth deficits.
Figure 4  Scatterplot of radius length against age of Medieval Islamic children (circle) and Late Medieval Christian children (square), compared to the Denver Growth study mean (solid line), one standard deviation (short dash), and two standard deviations (long dash).
Table 3  Sample size (n), mean (\(\bar{x}\)), and standard deviation (SD) for radius diaphyseal length z-scores, broken down by time period and by age (below age two and at age two and above). Kruskal-Wallis test compared Early Islamic, Late Islamic, Early Christian, and Late Christian periods.

<table>
<thead>
<tr>
<th>Radius Diaphyseal Length Z-Score</th>
<th>Total</th>
<th>Islamic Total</th>
<th>Early Islamic</th>
<th>Late Islamic</th>
<th>Christian Total</th>
<th>Early Christian</th>
<th>Late Christian</th>
<th>Kruskal-Wallis</th>
</tr>
</thead>
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<td>SD</td>
<td>n</td>
<td>(\bar{x})</td>
<td>SD</td>
<td>n</td>
<td>(\bar{x})</td>
</tr>
<tr>
<td>Total</td>
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<td>1.77</td>
<td>19</td>
<td>-1.83</td>
<td>1.82</td>
<td>13</td>
<td>-2.04</td>
</tr>
<tr>
<td>Age &lt;2</td>
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<td>-0.91</td>
<td>1.57</td>
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<td>-0.99</td>
<td>1.61</td>
<td>7</td>
<td>-0.97</td>
</tr>
<tr>
<td>Age ≥2</td>
<td>17</td>
<td>-2.84</td>
<td>1.46</td>
<td>6</td>
<td>-2.99</td>
<td>1.15</td>
<td>6</td>
<td>-2.32</td>
</tr>
</tbody>
</table>
Ulna.

Ulna diaphyseal length for age was found to be stunted (z-score $\bar{x}=-1.84$) in relation to the reference data. This degree of stunting was found to be statistically significant using the one sample t-test ($t=-4.910$, $p=0.000$). Figure 5 shows ulna diaphyseal length for age compared to the Denver Growth Study. Change through time is less obvious in the total ulna z-score results. For the total sample, growth deficits through time were more or less the same, as there was minimal change between the earliest and latest periods (see Table 4). When examining the results by age category, growth deficits are approximately equal for the earliest and latest periods for those less than two years of age (see Table 4). For those two years of age or more, growth deficit lessens through time, however, this change is not until the latest period (See Table 4). None of the results, examined as changes through time were statistically significant, shown in Table 4. The Mann-Whitney test showed that differences between age categories z-score means were statistically significant ($Z=-2.924$, $p=0.003$). This shows that there were increased growth deficits for the older children.
Figure 5 Scatterplot of ulna length against age of Medieval Islamic children (circle) and Late Medieval Christian children (square), compared to the Denver Growth study mean (solid line), one standard deviation (short dash), and two standard deviations (long dash).
Table 4  Sample size (n), mean (\( \bar{x} \)), and standard deviation (SD) for ulna diaphyseal length z-scores, broken down by time period and by age (below age two and at age two and above). Kruskal-Wallis test compared Early Islamic, Late Islamic, Early Christian, and Late Christian periods.

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Islamic Total</th>
<th>Early Islamic</th>
<th>Late Islamic</th>
<th>Christian Total</th>
<th>Early Christian</th>
<th>Late Christian</th>
<th>Kruskal-Wallis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>( \bar{x} )</td>
<td>SD</td>
<td>n</td>
<td>( \bar{x} )</td>
<td>SD</td>
<td>n</td>
<td>( \bar{x} )</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>-1.84</td>
<td>2.02</td>
<td>20</td>
<td>-1.77</td>
<td>1.97</td>
<td>13</td>
<td>-1.86</td>
</tr>
<tr>
<td>Age &lt;2</td>
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<td>-0.76</td>
<td>1.70</td>
<td>13</td>
<td>-0.85</td>
<td>1.82</td>
<td>7</td>
<td>-0.44</td>
</tr>
<tr>
<td>Age ≥2</td>
<td>14</td>
<td>-3.00</td>
<td>1.70</td>
<td>6</td>
<td>-3.49</td>
<td>0.62</td>
<td>1</td>
<td>-3.30</td>
</tr>
</tbody>
</table>
**Femur.**

The femur presents with growth deficits, based on the total z-score mean ($\bar{x}=-2.14$) in relation to the reference data. This linear stunting was found to be statistically different in comparison to the reference data using the one sample t-test ($t=-4.743$, $p=0.000$). This is clearly illustrated in Figure 6, where femur length for age is plotted against expected growth from the Denver Study. We saw an increase in growth deficits through time, shown in Table 5. These changes through time are illustrated in Figures 7, which displays femur length-for-age for Early and Late Islamic periods, and Figure 8, which shows femur length-for-age for Early and Late Christian periods. For those less than two years of age, there was an decrease in growth deficits through time, although our sample does not include any in the Late Christian Period (see Table 5). For those two years of age and older, there was also an decrease in growth deficits through time, shown in Table 5. The Kurskal-Wallis did not detect significant change when examining z-score growth deficits through time. The Mann-Whitney test showed that differences in age category z-score means (see Table 5) were statistically significant ($Z=-2.792$, $p=0.004$). This indicates that older individuals had increased growth deficits.
Figure 6  Scatterplot of femur length against age of Medieval Islamic children (circle) and Late Medieval Christian children (square), compared to the Denver Growth study mean (solid line), one standard deviation (short dash), and two standard deviations (long dash).
Figure 7  Scatterplot of femur length against age of Early Islamic children (circle) and Late Islamic children (square), compared to the Denver Growth study mean (solid line), one standard deviation (short dash), and two standard deviations (long dash).
Figure 8  Scatterplot of femur length against age of Early Christian children (circle) and Late Christian children (square), compared to the Denver Growth study mean (solid line), one standard deviation (short dash), and two standard deviations (long dash).
Table 5  
Sample size (n), mean (\(\bar{x}\)), and standard deviation (SD) for femur diaphyseal length z-scores, broken down by time period and by age (below age two and at age two and above). Kruskal-Wallis test compared Early Islamic, Late Islamic, Early Christian, and Late Christian periods.

<table>
<thead>
<tr>
<th>Femur Diaphyseal Length Z-Score</th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Islamic Total</td>
<td>Early Islamic</td>
<td>Late Islamic</td>
<td>Christian Total</td>
<td>Early Christian</td>
<td>Late Christian</td>
<td>Kruskal-Wallis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>(\bar{x})</td>
<td>SD</td>
<td>n</td>
<td>(\bar{x})</td>
<td>SD</td>
<td>n</td>
<td>(\bar{x})</td>
<td>SD</td>
<td>n</td>
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<td>SD</td>
</tr>
<tr>
<td>Total</td>
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<td>-2.14</td>
<td>2.25</td>
<td>17</td>
<td>-1.95</td>
<td>2.15</td>
<td>10</td>
<td>-2.23</td>
<td>2.42</td>
<td>7</td>
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<td>-0.85</td>
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<td>5</td>
<td>-0.44</td>
<td>1.78</td>
<td>5</td>
<td>-1.26</td>
<td>1.89</td>
</tr>
<tr>
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<td>4.45</td>
<td>7</td>
<td>-3.53</td>
<td>1.62</td>
<td>5</td>
<td>-4.02</td>
<td>1.41</td>
<td>2</td>
<td>-2.29</td>
<td>1.89</td>
</tr>
</tbody>
</table>


Tibia.

The tibia mean z-score shows a significant growth deficit ($\bar{x}=-2.05$), which is statically different than the reference data ($t=-4.500$, $p=0.000$). Linear growth attainment compared to the reference sample is shown in Figure 9. When examining tibia results as a whole, there is an increase in growth deficits over time, shown in Table 6. However, when examining the results by age category, this pattern changes. Individuals less than two years of age had decreased growth deficits through time, although there are no results for the Late Christian Period. Individuals two years or more also show a decrease in growth deficits through the Early Christian phase, until the Late Christian phase when growth deficits increase. Any of the tests to examine change through time were not found to be statistically significant, shown in Table 6. The Mann-Whitney test shows that differences between age categories z-score means (see Table 6) were statistically significant ($Z=-3.416$, $p=0.000$). This shows that older individuals experienced increased growth deficits.
Figure 9  Scatterplot of tibia length against age of Medieval Islamic children (circle) and Late Medieval Christian children (square), compared to the Denver Growth study mean (solid line), one standard deviation (short dash), and two standard deviations (long dash).
Table 6  Sample size (n), mean (\(\bar{x}\)), and standard deviation (SD) for tibia diaphyseal length z-scores, broken down by time period and by age (below age two and at age two and above). Kruskal-Wallis test compared Early Islamic, Late Islamic, Early Christian, and Late Christian periods.

<table>
<thead>
<tr>
<th>Tibia Diaphyseal Length Z-Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Age  &lt;2</td>
</tr>
<tr>
<td>Age  ≥2</td>
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<td></td>
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</tbody>
</table>

Kruskal-Wallis test compared Early Islamic, Late Islamic, Early Christian, and Late Christian periods.
Fibula.

The fibula had the smallest sample size (n=13). There were no individuals from the Late Christian sample to contribute to the results and, therefore, we have a limited understanding of how fibula diaphyseal length changes through time. The z-score mean reflects significant growth stunting ($\bar{x}=-2.13$) when compared to the reference data, reflected in the one-sample t-test result ($t=-2.768$, $p=0.017$). Fibula diaphyseal length is plotted against the reference data in Figure 10. Individuals that were less than two years old exhibited decreased growth deficits through time. Individuals who were two years old or more presented with increased growth deficits through time. Results that examined change in growth through time were not found to be statistically significant, shown in Table 7. There were differences in age category z-score means (see Table 7). Using the Mann-Whitney test, these differences were found to be statistically significant ($Z=-2.857$, $p=0.002$).
Figure 10  Scatterplot of fibula length against age of Medieval Islamic children (circle) and Late Medieval Christian children (square), compared to the Denver Growth study mean (solid line), one standard deviation (short dash), and two standard deviations (long dash).
Table 7: Sample size (n), mean (\(\bar{x}\)), and standard deviation (SD) for fibula diaphyseal length z-scores, broken down by time period and by age (below age two and at age two and above). Kruskal-Wallis test compared Early Islamic, Late Islamic, Early Christian, and Late Christian periods.

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<th>Early Islamic</th>
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<th>Christian Total</th>
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<td>SD</td>
<td>n</td>
<td>(\bar{x})</td>
<td>SD</td>
<td>n</td>
<td>(\bar{x})</td>
</tr>
<tr>
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<td>2.77</td>
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<td>-5.11</td>
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<td>4</td>
<td>-5.11</td>
</tr>
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</table>
Cortical/appositional growth

Total area.

Overall, the total area z-score mean of the femur midshaft shows a significant growth deficit ($\bar{z}=-2.03$) in relation to the reference data, illustrated in Figure 11. This z-score mean was found to be statistically different from expected growth using the one sample t-test ($t=-7.460$, $p=0.000$). When the age categories were examined by small time periods, we saw a pattern of increased growth deficits in those under the age of two, whereas for older juveniles, we saw little change in growth deficits between the earliest and latest time periods, shown in Table 8. Results over time were found to be statistically insignificant (see Table 8). Mean z-scores were not statically significant between age categories (see Table 8) ($Z=-0.066$, $p=0.974$).
Figure 11  Scatterplot of femur midshaft total area against age of Medieval Islamic children (circle) and Late Medieval Christian children (square), compared to the Denver Growth study mean (solid line), one standard deviation (short dash), and two standard deviations (long dash).
Table 8  Sample size (n), mean (\(\bar{x}\)), and standard deviation (SD) for femur midshaft total area z-scores, broken down by time period and by age (below age two and at age two and above). Kruskal-Wallis test compares Early Islamic, Late Islamic, Early Christian, and Late Christian periods.

<table>
<thead>
<tr>
<th>Total Area Femur Midshaft Z-Score</th>
<th>Total Hindu Total</th>
<th>Early Hindu</th>
<th>Late Hindu</th>
<th>Christian Total</th>
<th>Early Christian</th>
<th>Late Christian</th>
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<td>SD</td>
<td>n</td>
<td>(\bar{x})</td>
<td>SD</td>
<td>n</td>
<td>(\bar{x})</td>
</tr>
<tr>
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</tr>
<tr>
<td>Age ≥2</td>
<td>12</td>
<td>-2.10</td>
<td>1.23</td>
<td>6</td>
<td>-2.21</td>
<td>0.84</td>
<td>4</td>
</tr>
<tr>
<td>Kruskal-Wallis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cortical area.

The cortical area z-score mean of the femur midshaft shows a growth deficit ($\bar{x} = -2.02$), when compared to the reference data. Using the one sample t-test, the z-score mean was significantly different from zero ($t=-4.521$, $p=0.000$). As illustrated in Figure 12, only two individuals meet or exceed the mean for expected growth. Overall, there were increased growth deficits through time, shown in Table 9; these increased growth deficits are also seen when examining z-scores by small time period (Early Islamic, Late Islamic, Early Christian, Late Christian). Individuals that were under the age of two present with increased growth deficits through time and individuals two years old or more show decreased growth deficits through time. Any test that examined differences through time was found to be not statistically significant. When comparing cortical area by age category using the Mann Whitney test, z-score means show that older individuals experienced increased growth deficits compared to younger children (see Table 10). This difference in age categories means was significant ($Z=-2.308$, $p=0.021$).
Figure 12  Scatterplot of femur midshaft cortical area against age of Medieval Islamic children (circle) and Late Medieval Christian children (square), compared to the Denver Growth study mean (solid line), one standard deviation (short dash), and two standard deviations (long dash).
Table 9  Sample size (n), mean (\(\bar{x}\)), and standard deviation (SD) for femur midshaft cortical area z-scores, broken down by time period and by age (below age two and at age two and above). Kruskal-Wallis test compared Early Islamic, Late Islamic, Early Christian, and Late Christian periods.

<table>
<thead>
<tr>
<th>Cortical Area Femur Midshaft Z-Score</th>
<th>Total</th>
<th>Islamic Total</th>
<th>Early Islamic</th>
<th>Late Islamic</th>
<th>Christian Total</th>
<th>Early Christian</th>
<th>Late Christian</th>
<th>Kruskal-Wallis</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>x</td>
<td>SD</td>
<td>n</td>
<td>x</td>
<td>SD</td>
<td>n</td>
<td>x</td>
<td>SD</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>-2.02</td>
<td>2.10</td>
<td>15</td>
<td>-1.82</td>
<td>2.07</td>
<td>9</td>
<td>-2.23</td>
</tr>
<tr>
<td>Age &lt;2</td>
<td>10</td>
<td>-0.78</td>
<td>1.44</td>
<td>9</td>
<td>-0.67</td>
<td>1.48</td>
<td>5</td>
<td>-0.56</td>
</tr>
<tr>
<td>Age ≥2</td>
<td>12</td>
<td>-3.06</td>
<td>2.03</td>
<td>6</td>
<td>-3.55</td>
<td>1.98</td>
<td>4</td>
<td>-4.30</td>
</tr>
</tbody>
</table>
Cortical thickness.

The femoral midshaft cortical thickness z-score mean shows a growth deficit, relative to the reference data (\( \bar{x} = -1.04 \)) (see Figure 13). The z-score mean was found to be different when compared to zero (\( t = -2.024, p = 0.056 \)). Overall, there are increased growth deficits through time, shown in Table 10. When examining change in those under the age of two, there is a decrease of growth deficits. Those who were two years old or more, have a decrease in growth deficits. None of the results were found to be statistically significant, when examining change through time (see Table 10). When comparing cortical area by age category, z-score means (see Table 10) show that older individuals experience increased growth deficits when compared with younger individuals (\( Z = -3.297, p = 0.000 \)).
Figure 13  Scatterplot of femur midshaft cortical thickness against age of Medieval Islamic children (circle) and Late Medieval Christian children (square), compared to the Denver Growth study mean (solid line), one standard deviation (short dash), and two standard deviations (long dash).
Table 10  Sample size (n), mean (\(\bar{x}\)), and standard deviation (SD) for femur midshaft cotical thickness z-scores, broken down by time period and by age (below age two and at age two and above). Kruskal-Wallis test compared Early Islamic, Late Islamic, Early Christian, and Late Christian periods.

<table>
<thead>
<tr>
<th>Cortical Thickness Femur Midshaft Z-Score</th>
<th>Total</th>
<th>Islamic Total</th>
<th>Early Islamic</th>
<th>Late Islamic</th>
<th>Christian Total</th>
<th>Early Christian</th>
<th>Late Christian</th>
<th>Kruskal-Wallis</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>x</td>
<td>SD</td>
<td>n</td>
<td>(\bar{x})</td>
<td>SD</td>
<td>n</td>
<td>(\bar{x})</td>
<td>SD</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>-1.04</td>
<td>242</td>
<td>15</td>
<td>-0.83</td>
<td>2.73</td>
<td>9</td>
<td>-1.40</td>
</tr>
<tr>
<td>Age &lt;2</td>
<td>10</td>
<td>0.64</td>
<td>2.15</td>
<td>9</td>
<td>0.62</td>
<td>2.28</td>
<td>5</td>
<td>0.54</td>
</tr>
<tr>
<td>Age (\geq)2</td>
<td>12</td>
<td>-2.45</td>
<td>1.63</td>
<td>6</td>
<td>-2.99</td>
<td>1.76</td>
<td>4</td>
<td>-3.82</td>
</tr>
</tbody>
</table>
Medullary area.

Medullary area values for each individual were plotted against the reference data in Figure 14. The z-score mean for the femoral midshaft medullary area ($\bar{x} = -0.93$) was found to be statistically different from zero ($t = -3.352$, $p = 0.003$), indicating a significant growth deficit in the sample. Changes in the medullary area appear somewhat stationary over time and by age, shown in Table 11. However, once z-score results were examined in higher resolution by time and age, changes in growth deficits were visible (see Table 11). Medullary area growth deficits increase though time in those under the age of two and in those two years old or more. Any result that examined change through time was not found to be statistically significant, shown in Table 11. When analyzing the z-score means between the two age categories (see Table 11) the difference between them was statistically different ($Z = -2.110$, $p = 0.035$). This shows that younger individuals experienced a significantly greater growth deficit.
Figure 14  Scatterplot of femur midshaft medullary area against age of Medieval Islamic children (circle) and Late Medieval Christian children (square), compared to the Denver Growth study mean (solid line), one standard deviation (short dash), and two standard deviations (long dash).
Table 11  Sample size (n), mean (\( \bar{x} \)), and standard deviation (SD) for femur midshaft medullary area z-scores, broken down by time period and by age (below age two and at age two and above). Kruskal-Wallis test compares Early Islamic, Late Islamic, Early Christian, and Late Christian periods.

<table>
<thead>
<tr>
<th>Medullary Area Femur Midshaft Z-Score</th>
<th>Total</th>
<th>Islamic Total</th>
<th>Early Islamic</th>
<th>Late Islamic</th>
<th>Christian Total</th>
<th>Early Christian</th>
<th>Late Christian</th>
<th>Kruskal-Wallis</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>x</td>
<td>SD</td>
<td>n</td>
<td>x</td>
<td>SD</td>
<td>n</td>
<td>x</td>
<td>SD</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
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<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>-0.93</td>
<td>1.30</td>
<td>15</td>
<td>-0.96</td>
<td>1.46</td>
<td>9</td>
<td>-0.69</td>
</tr>
<tr>
<td>Age &lt;2</td>
<td>10</td>
<td>-1.59</td>
<td>1.57</td>
<td>9</td>
<td>-1.48</td>
<td>1.62</td>
<td>5</td>
<td>-1.32</td>
</tr>
<tr>
<td>Age ≥2</td>
<td>12</td>
<td>-0.38</td>
<td>0.69</td>
<td>6</td>
<td>-0.19</td>
<td>0.76</td>
<td>4</td>
<td>0.11</td>
</tr>
</tbody>
</table>
Chapter 5. DISCUSSION

Although the results showed no statistically significant difference through time and, therefore, no conclusion can be drawn from this, the increase in growth deficits of the ulna, radius, femur, tibia, and fibula during the Christian periods could suggest that extrinsic stress was amplified after a period of decreased growth deficits, possibly due to improved living conditions and the social environment. This could be a reflection of the effects of Islamic social improvements before social conditions shifted during and after the Christian conquest. However, we do not know if there were any improvements with the introduction of Islamic people to the Iberian Peninsula because there is no baseline from the earlier Visigoth occupation of Santarém for comparison. Remains from this period could not be analyzed due to poor preservation and extremely small sample size.

Statistically significant growth deficits in the Late Medieval Christian period could not be confirmed. The lack of statistically significant results reflects two outcomes. Size for the total sample and sub-populations impacted the study to a degree in which statistically significant changes in growth and development cannot be identified. The other outcome is that because this study spans several centuries, only large trends will be detected, where small changes will be hidden. The sample size may have had a large role in the lack of statistically significant results despite noticeable trends. This is based on our findings of an overall stressed population and our understanding of the social environment, living conditions, and social practices within the Medieval Islamic and Late Medieval Christian Periods. While we cannot evaluate how growth and development were impacted differently in the Medieval Periods, we can state that growth deficits were exhibited throughout the periods of study. Because we know the greater role that environmental conditions have on growth, over genetic variation, we can assume that extrinsic stress is the driving force behind growth deficits in this sample. We cannot assess what extrinsic stresses and social determinates of health directly or indirectly affected these populations through the observed sample-wide growth deficit due to this study’s data constraints. We can state, however, that the overall impact to growth present in this sample indicates that this was caused by extrinsic stress, driven by the social environment and the social determinates of health that accompany this.
The linear growth z-score means in this study indicate that for combined age categories and for those two years and older, we see a pattern of initial decreased growth deficits through the Early to Late Islamic Periods, before an increase of growth deficits in the Early and Late Christian Periods. This could reflect the effects that the Medieval Islamic Period had; with the introduction of improvements to the social and physical environment causing a decrease in extrinsic stress and then the conquest and Late Medieval Christian Period, which introduced new extrinsic stress. There is also a similar pattern of increased cortical bone loss through time when comparing the Islamic and Christian Periods for total area, cortical area, and cortical thickness. This pattern of increased growth deficits from the Medieval Islamic to Late Medieval Christian Period is seen throughout the sample. While not statistically significant, it needs to be further explored as it may be indicative of increased extrinsic stress through worsening living conditions for children and the overall population during the transition from Islamic to the Christian Period. This pattern of increased stress due to environmental constraints caused by the Christian conquest and subsequent migration and population stress has been suggested by Robles and colleagues (1991) because in their study, they found a higher mortality rate in the population directly preceding the Christian conquest.

The results indicate that based on the ten variables of linear and appositional growth, the majority of children in the sample experienced significant stress in their lifetime, to the degree that it impacted growth through long bone and appositional bone growth deficits, when compared with the Denver Growth Study. This indicates that the social environment and living conditions were impacting growth in Medieval Santarém, as compared to modern day children. The lower limb, the femur, tibia, and fibula, have the lowest z-score means, indicating that the lower limb was the most stunted. This shows that extrinsic stress was present and significantly affected growth, as the lower limb is known to be most impacted by living conditions (Cameron & Bogin, 2012; Cardoso, 2005). This indicates that while the social environment may have changed through time with the introduction of Islamic knowledge and lifeways and then the Christian conquest and Christian lifeways, extrinsic stress causing growth deficits was present throughout the entirety of the Medieval Period. This comparable distribution of extrinsic stress through time is supported in the understanding that childhood mortality was high throughout the Medieval world (Gil'adi, 1992).
Within the sample, variation by age category was often significant, where older children experienced increased growth deficits. This variation in age would suggest that older children were experiencing an accumulation of stress that increased the growth deficit through time. The cumulative effect of growth deficits due to environmental constraints, such as living conditions, as children age is known to occur (Cardoso, Abrantes, & Humphrey, 2014; Eveleth & Tanner, 1990). In all linear results, individuals under the age of two presented with lessened growth deficits than those who were older. This pattern of increased growth deficits for older children was also found in the femur midshaft cortical area and cortical thickness results. The differences in growth deficits were significant, reflecting an accumulation of stress, which may be due to the practice of weaning at two years of age (Gil’adi, 1992), the slowing of growth velocity after age two (Cameron & Bogin, 2012), and the increased role in extrinsic factors on growth and development as children become less dependent on maternal health and care (Goodman & Armelagos, 1989; Lewis, 2007).

The appositional bone results indicate an interesting pattern for failure of cortical development; there were significant results when examining the z-score means based on age category. We saw that total area was the most impacted aspect of appositional growth, resulting in smaller diameter for age and bones that appeared atrophied. There was a deficit in total area development, but it was not significantly different between children under the age of two and older children. However, z-score means for cortical area, cortical thickness, and medullary area were all significantly different for those two years old or more. The z-score means for cortical area and cortical thickness show signs of decreased bone deposition for older individuals. As proposed above, this shift of increased growth deficits in older individuals could be caused by the social environment and poor living conditions having an accumulation effect.

The ratio of cortical area and medullary area indicates that the apposition of cortical bone is the most effected aspect of this growth, causing the small total area. There was decreased deposition of cortical bone on the periosteal surface and a lack of resorption within the medullary cavity. This indicates that stress caused a significant disruption to the normal rate of bone remodelling resulting from a lack of periosteal deposition for the femur midshaft cortical bone. Because the z-score for cortical area and cortical thickness was much lower than medullary area, this suggests that deposition of periosteal new bone was causing the smaller-for-age result. While other
researchers have suggested that the most cortical bone thinning is due to endosteal resorption (Garn et al., 1969; Mays et al., 2009), this pattern of a lack of periosteal apposition has been found in children (Himes et al., 1975; Huss-Ashmore, 1981). While we cannot determine which extrinsic stress may be interfering with the development of cortical bone on the periosteal surface, we know that social determinates of health, including malnutrition and lower socio-economic status, have been found to cause similar results (Garn et al., 1969; Mays et al., 2009; Ruff et al., 2013). Furthermore, the z-score means for the total sample’s cortical area and cortical thickness closely mirrors the z-score means for femur length, suggesting that this lack of deposition is similar to the linear stunting.

Although the Medieval Period is portrayed as a difficult time, previous research has examined whether children in Late Medieval Christian Portugal experienced significant growth deficits, which was attribute to differing levels of stress. When compared with youth from the industrial era in early 20th century Portugal, Cardoso and Garcia (2009) found that early childhood growth during the Late Medieval Christian Period did not differ significantly, suggesting that the Medieval Period was not any worse and perhaps better than the Modern Period. Cardoso and Garcia (2009) did find that when analyzing Late Medieval Christian children using the same methodology and reference population as this study, their analysis of femur length for age resulted in a z-score mean of -2.23. This differs only slightly from this study’s results, and falls in-between the Medieval Islamic z-score mean of -1.95 and Late Medieval Christian z-score mean of -2.52. Furthermore, other research has shown that the Medieval Islamic period in Santarém was a time of stress, through both the frequency of enamel defects and evidence for parasitic infection within their sample from Largo Cândido dos Reis (Cunha, Santos, Matias, & Sianto, 2017). High child and infant mortality was present in Islamic Spain. Robles and colleagues (1991) found in their study both growth deficits in children and a high death rate for those under the age of two, which they attributed to forced migration and the resulting spread of disease and malnutrition, as the Christian conquest pushed south. These three projects show that preconceived notions of how a period may be more or less stressful based on historical records of the social environment may not be accurate. These studies also suggest that extrinsic factors affecting growth and development, such as the social determinates of health, during the Medieval Periods were not isolated to our sample from Santarém, Portugal.
Study limitations and Future directions.

We faced limitations in this project that may have impacted the outcome based on the scale and resolution of the study. Due to the large time intervals in our study, current evidence can only capture broad trends of differences and cannot detect small scale or time-specific change. We also expected the largest number of skeletal remains to be under the age of five, based on understanding of mortality patterns (Lewis, 2007); however, there was an obvious lack of young juveniles in the Late Medieval Christian sample. While this may be suggestive of a mortality bias (Wood et al., 1992), in that more infants were dying in the Medieval Islamic Period than in the Late Medieval Christian Period, it is far more likely that the age distribution seen in this sample is due to a cultural mortality bias (Saunders & Hoppa, 1993), as we know that Islamic infant burials were in separate areas (Petersen, 2013) and Christian infants and children were preferentially buried within the church (Hausmair, 2017). There was also a sampling and excavation bias (Cardoso, 2004), where the cemeteries in Santarém were not fully excavated and not all internments were removed. These proposed biases would affect this study through the representativeness of age and sample size by time period. We minimized this bias through the use of z-scores which standardized results by comparing the relative distance to the expected mean for age, rather than attained growth for age.

Another major consideration for this study is the age we assigned to each individual. We used dental age, over skeletal development because dental development is less impacted by environmental conditions (Cardoso, 2009). While we are confident in our methods, due to preservation, in some cases only a single tooth was used to provide an age estimate. For seven individuals only one tooth was available for use, however, this only introduces a small amount of variation for deciduous dentition (0.20-0.14 years) (Cardoso, 2007) and slightly more for permanent dentition (0.56-0.05 years) (Cardoso, 2009). Potential effects for age variation could place individuals in a different age category for z-score calculations; however, as multiple teeth were used when possible for age estimations and for single tooth estimations most expected variation is within a half-year range, this would not have great impact on age estimations as it would only likely shift an individual by one age bracket, which has little effect.

Other limitations due to human error are possible, as in any study. Potential avenues that introduced error into this study include measurement, transcription, and
instrument errors. However, prior to data collection conducted by myself, detailed protocols were written and practiced, which was supervised by Hugo Cardoso. This would have limited the potential for data collection errors, including measuring. Transcription errors were limited through a detailed recording protocol as well as detailed scaled photos for all bones. To prevent instrument errors, calipers were checked regularly for accuracy and scaled radiographs were taken and checked, to ensure correct positioning of teeth and femora.

Future research is planned to further address how these samples relate to each other. This will be achieved through radiocarbon dating for the sites to further unpack the temporal relations between sites, aDNA analysis to examine sex representation within the sample and haploid group membership, and isotope analysis to examine diet and migration within and between groups. An expansion of this project to other Portuguese cities and town that experienced both Islamic and Christian occupation would help to address the small sample size and mitigate our concerns about the current limitations of the study. An increased sample size of both linear and appositional data would enhance this project. If preservation conditions were better and the sample expanded, then the inclusion of non-specific indicators of stress, such as enamel defects, cribra orbitalia, and periostitis would expand on interpretations of extrinsic stress. Unfortunately for this study, preservation was a significant problem. By exploring more methods for analysis based on this sample, a more detailed understanding of juvenile growth and development in Medieval Santarém and Portugal will be achieved.
Chapter 6. CONCLUSION

This research shows that when compared to the Denver Growth Study, medieval juveniles of Santarém experienced stress which caused significant growth deficits in linear and appositional growth, which resulted in the stunting of long bones and a reduction in periosteal development. We anticipated seeing improved growth in the Medieval Islamic Period when compared with the Late Medieval Christian Period. Our expectations were based on the historical understanding of the Golden Age of Islam and the improved social determinates of health, including nutrition through diet diversity, an appreciation for hygiene, pediatric care, and urbanization. Despite not detecting a significant level of change through time and having a small sample, there was an interesting trend in increased growth deficits over time. This result shows that in the Medieval Period, extrinsic stress, such as those caused by the social environment including nutrition, disease, socio-economic status, and urbanization, negatively affected the lives of these children. As growth deficits were present throughout the juvenile population, we can ascertain that this was caused by extrinsic stress. Therefore, when compared to a modern reference sample, the entire population of Santarém can reasonably be described as having experienced stress caused by the social environment during the Medieval Period.
LITERATURE CITED


(Boyd Orr) Survey of Diet and Health in Pre-war Britain. *Journal of Epidemiology & Community Health*, 52(3), 142–152.


