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Abstract: Constitutional growth delay in subadults may be caused by chronic illness, malnutrition, and/or undernutrition. Very little is known about the community health of the presumptive forager-farmers of the Late Woodland (~ AD 900-1150) period site of Schroeder Mounds (Henderson County, Illinois). In an effort to increase understanding of community health, the subadults (N=15) were examined by age-at-death for evidence of growth stunting as reflected in forelimb shortening. Crural and brachial indices were calculated for those subadults preserving measurable femora and tibiae and/or measurable humeri and radii. These indices were compared by age category to indices calculated from normal bone lengths taken from published clinical data. Stunting was evident for all ages-at-death in the Schroeder Mounds sample. The stunting was contextualized by assessing the presence/absence of potentially causative or synergistically related skeletally visible chronic health stress indicators (i.e., porotic hyperostosis, cribra orbitalia, linear enamel hypoplasia, periostosis). The results indicated that all subadults exhibited growth stunting regardless of the presence of the quantified health issues. This may suggest that stunting is potentially a free-standing osteological marker of developmental stress. Within Schroeder Mounds, stunting may ultimately be due to various environmental (e.g., harvest or resource shortfall) and cultural (e.g., weaning, child labor) factors.

Keywords: Subadults, Late Woodland Period, Schroeder Mounds, Illinois, growth stunting

Introduction

In affluent societies, subadults are presumed to reach their genetic growth potential (de Onis and Blössner 2003; de Onis et al. 2012; Waterlow 1994). However, growth stunting is routinely observed in substandard or impoverished socioeconomic circumstances (e.g., Black et al. 2008; de Onis et al. 2012; Lin et al. 2013; Lun 2002; Lundeen et al. 2014; Nobarro et al. 1988; Piperata 2007; Worthen et al. 2001). This is particularly problematic for very young children and infants as environmentally and culturally determined events (e.g., early weaning) additionally and differentially affect immature immune systems and their increased nutritional needs for growth and development (Baxter 2005; Lewis 2007; Schillaci 2011; Schweich and Knüsel 2003). However, stunting may be difficult to quantify. Absolute bone length may reflect either short stature or compromised subadult growth (Bogin and Varela-Silva 2010; Lai 2006; Vischer 2008; Waterlow 1994). In archaeologically-based subadult samples with no direct data about community health and hygiene, it is often unclear if long bone length is quantifying population-specific stature or growth stunting (Flores-Mir et al. 2005; Vercellotti 2012). This is particularly compounded as skeletal age-at-death is an age range and may not be congruent to chronological age (Buikstra and Ubelaker 1994).

In archaeological skeletal samples, compromised growth is routinely identified by evaluating long bone length relative to developmental age against some standard or subsistence-settlement controls (Crane-Kramer et al. 2007; Gunnell et al. 2001; Ribot and Roberts 1996; Zakrzewski 2003). This is often corroborated by co-association with chronic health stressors visible on dry bone (i.e., periostosis, porotic hyperostosis, linear enamel hypoplasia, cribra orbitalia) (e.g., Agnew et al. 2014; Buckley 2000; Cardoso 2005; Humphrey 2000; Kemkes-Grottenthaler 2005; Lewis 2007; Mays et al. 2009; MacCord 2009; Pardo 2011; Pinhasi et al. 2005; Roberts and Manchester 2007; Ribot and Roberts 1996; Schillaci et al. 2011; Waldren 2009). Archaeologically, this can be meaningful as stunting has been documented to co-associate with subsistence, settlement, and sociopolitical changes (Blackwell et al. 2009; Cardoso 2005; Crane-Kramer et al. 2007; Claassen 2002; Mummert et al. 2011; Petroutsa and Manolis 2007; Pinhasi et al. 2005; Ribot and Roberts 1996; Shell-Duncan and Obiero 2000). However, in archaeological samples with few subadults and little or no subsistence-settlement context, stunting may be difficult to segregate from stature.

One clinical measure of compromised growth that is independent of stature is forelimb foreshortening (Crimmins and Finch 2006; Dewey and Mayers 2011; Harrison 1992; Lewit and Kerrebrock 1997; Lunn 2002; Nebarro et al. 1988). With nutritional and/or medical intervention, distal limb catch-up growth is possible (e.g., Coly et al. 2006; Lundeen et al. 2014; Palacios 2011), otherwise foreshortening is likely permanent. Paleopathologically meaningful, foreshortening may be a predictor of premature death (e.g., Black et al. 2008; Crimmins and Finch 2006; Norgan 2000; Victora et al. 2008).

Context of the Schroeder Mound Site

The Late Woodland period in Illinois (~AD 650-1000) was a time of major subsistence, settlement, demographic, and sociopolitical changes (Esarey 2000; Nansel and Green 2000; Stoltman 2000; Studenmund 2000). It culminated in small-scale agriculture, political centralization, and large nucleated village settlements characteristic of the subsequent Mississippian period (~AD 1050-1350). The site of Schroeder Mounds (Figure 1) is a later Late Woodland (~AD 900-1150) burial context located along a bluff line in Henderson County, Illinois.

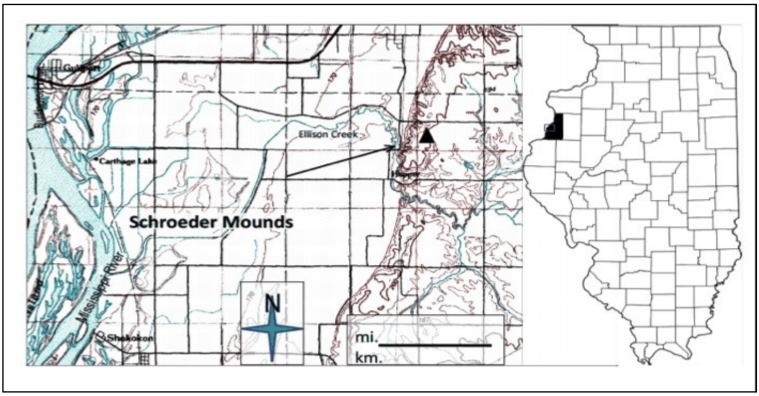

Figure 1: The location of the Schroeder Mounds mortuary site (black triangle) in the Mississippi River Valley of west-central Illinois indicated by the black triangle.

There is no subsistence-settlement information for this osteological sample (Kolb 2000; Riggle 1981). Therefore, only the skeletal material can reveal life-quality information, which can potentially be compared to other Illinois samples. The aim of this paper is to determine whether the Schroeder Mound subadults exhibited stunted growth in the forearm (ulna relative to the humerus) and foreleg (tibia relative to the femur), as the development in these particular skeletal regions is the most sensitive during subadult growth periods. It is possible that one or more of the suite of commonly quantified osteologically visible pathologies (i.e., periostosis, cribra orbitalia, linear enamel hypoplasia) has a synergistic, if not a causative, role in growth stunting.

Materials and Methods

Skeletal Aging

Although age ranges had already been assigned to each of the subadults (e.g., Dorsz 2012), they were re-assessed for the present study to corroborate or refine the age-at-death estimates. A subadult was defined as any individual with no more than two (maxillary and/or mandibular) third molars in occlusion. Subadult skeletal age was assessed by two methods: dental eruption sequence and epiphyseal fusion. The deciduous and permanent teeth were macroscopically evaluated for presence, level of visible crown-root development, and degree of alveolar eruption. Dental age was determined by the Massler and Shour dental development chart as reprinted in Ubelaker (1989) and White et al. (2011). The standards for epiphyseal fusion (Krogman and Iscan 1986; McKern and Stewart 1957; Redfield 1970; Suchey et al. 1984; Ubelaker 1989a, 1989b) were from Buikstra and Ubelaker (1994 43).

Quantifying Growth Stunting

Since absolute bone length may be a combination of genetic as well as environmental growth determiners, this study used the ratio of the forelimb to the proximal limb, a relationship that is independent of absolute length. Long bone stunting was determined by using the crural index (femur bicondylar length x 100/maximum tibial length) and the brachial index (maximum humeral length x 100/maximum radial length) (Buikstra and Ubelaker 1994, 46). The landmarks to determine the lengths are defined in the *Standards Manual* (Buikstra and Ubelaker 1994, Figures 14, 16, 17 & 18). A standard portable osteometric board (Paleotech Model FOB-P) was utilized. To reduce observer error, the bones were measured by one of the authors (Dorsz) and measurement was taken to the nearest millimeter. Intraobserver error was reduced by repeated blind study measurements to assure consistency of method and repeatability of the measurements. Out of fifty subadult skeletons, fifteen preserved long bones were complete enough to calculate a brachial and/or a crural index.

As absolute bone length is irrelevant to the calculated proportion of the brachial and crural indices, the comparative sample needed only to reflect the achievement of genetic length. The sample used was the long bone measurements of normal clinical data reported by biological age and sex in Maresh (1970). Since the sex of archaeologically derived skeletons of subadults cannot be reliably estimated, this study adopted the method of Schafer, Black, and Schuger (2009), which called for the average of Maresh's (1970) mean male and mean female tabular data that is, (n-male + n-female)/2, and graphed in half-year intervals from six months to age five and then by year to eighteen years. Three Schroeder Mounds subadults had unfused distal and fused proximal humeral epiphyses. The maximum lengths of those humeri were measured with the addition of the unfused epiphyses and are regarded here as estimated maximum lengths.

Because the sample size of the Schroeder Mounds subadults by age cohort was very small, no statistical tests were attempted. Stunting was assessed by visual comparisons of the cases to the calculated clinical indices.

Pathological Conditions

Various reactive changes observable on dry bone are indicative of health stress. Any one or more of these may affect linear growth. The most commonly quantified reactive changes are periostosis, cribra orbitalia, porotic hyperostosis, and linear enamel hypoplasia. Periostosis (Figure 2A) is reactive change to the bone cortex caused by dissemination of non-specific inflammation of the periosteum due to either mechanical injury or infection (Buckley 2000; Kim et al. 2013; Ortner 2003; Šlaus 2002). It was considered present in an individual if reactive change (either woven or mature bone) was present on at least one bone of the appendicular skeleton. Cribra Orbitalia (Figure 2B) is another pathological condition, and although its specific etiology is unclear (Holland and O'Brien 1997; Sullivan 2005; Walker et al. 2009; Wapler et al. 2004; Vaselech 2011), it is considered a good indicator of childhood stress. It was considered present if at least one orbit exhibited the slight stage of porotic pitting as defined by the *Standard*s Manual (Buikstra and Ubelaker 1994). The last condition Linear Enamel Hypoplasia (LEH) (Figure 2C) is a widely utilized non-specific stress indicator of the secondary dentition (Goodman and Armelagos 1988; Klaus, et al. 2009; Ribot and Roberts 1996). It was considered present if at least two authors identified a horizontal line across at least one permanent tooth.

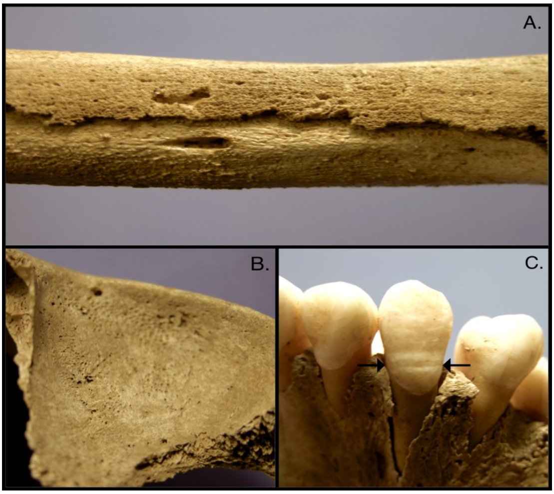

Figure 2: Examples from the Schroeder Mounds subadults for A) periostosis, B) cribra orbitalia, and C) linear enamel hypoplasia.

Results

Fifteen subadults from the Schroeder Mound sample preserve measurable long bones to calculate a brachial index, a crural index, or both. In Figure 3, the brachial index by chronological age of the Maresh-based samples indicates a steady ratio (between 10.7 to 11.2) until at or around puberty (circa twelve to thirteen years of age) when the forearm grows longer relative to the humerus (i.e., reduction of brachial index score), particularly after age fourteen. The brachial indices for the eleven Schroeder Mounds subadults are graphed across the comparative sample by the range of the skeletal age-at-death. No subadult from the Schroeder Mounds sample overlaps with the brachial index for any age category in the clinical sample. Indeed, the difference between the Schroeder Mounds sample and the clinical normal sample is greatest after age twelve. Considering the possibility that dry bone measurement error in the estimate of humeral length for the three adolescents (aged 12 –15 years, 15–18 years) may have underestimated humeral length, the difference may be greater (i.e., the indices may actually be higher). There is no consistent pattern of association between forearm stunting with the three stress indicators. That is, LEH is present on 33% of the subadult dentition, cribra orbitalia is present on 33% of the subadults, and periostosis is present on 8%. Stunting is also present on the 26% who exhibit no evidence of chronic health stress.

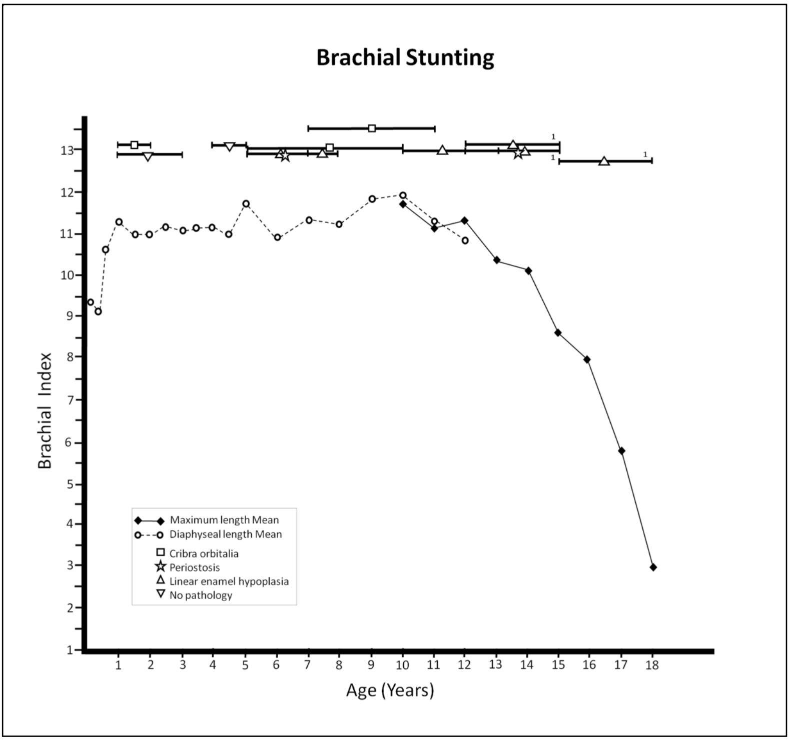

Figure 3: Brachial indices for eleven Schroeder Mounds subadults compared to the calculated brachial indices of the means for long bone length (Maresh 1970) by age in years. Schroeder cases with superscripts are based on estimated maximum humeral length on a diaphysis with preserved but unfused distal epiphyses.

Figure 4 displays the data for foreleg stunting (i.e., the crural index). Similar to the brachial index, the clinical sample exhibits a foreleg growth spurt at or around puberty with rapid relative growth occurring after age fourteen. Eleven individuals have measurable femora and tibiae to calculate an index. The Schroeder Mounds crural indices for the diaphyseal lengths are only slightly above the calculated normal indices. A marked departure occurs circa age thirteen and fourteen (at or near puberty). Two of the subadults with crural index data exhibit cribra orbitalia (18%); two subadults exhibit periostitis (18%); three exhibit linear enamel hypoplasia (27%). An absence of reactive change occurs in 36% of the small sample. It is possible that a different suite of Schroeder Mounds cases resulted in more congruence between the sample indices and the calculated normal pattern. Seven individuals preserve both arm and leg elements to enable a comparison of brachial and crural indices.

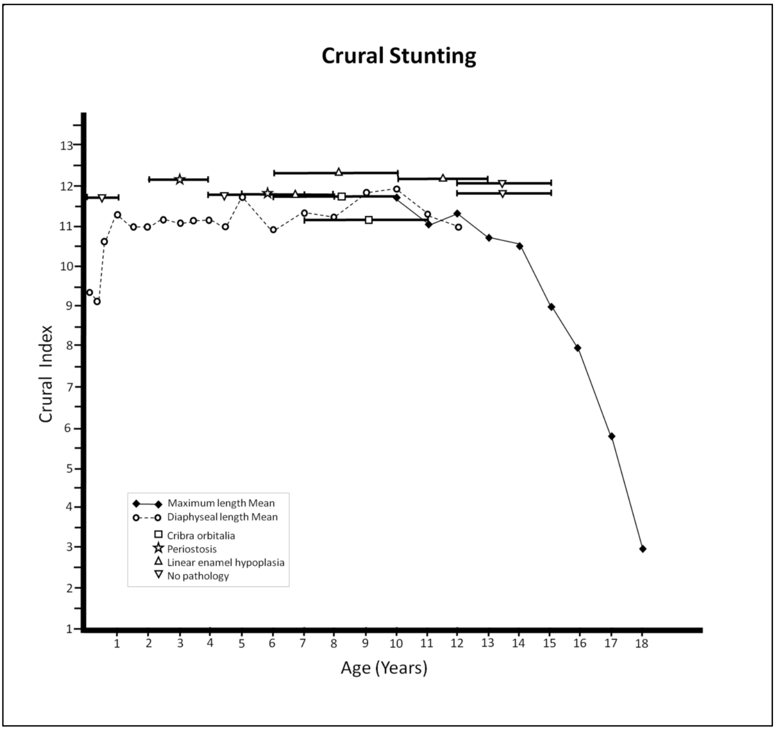

Figure 4: Crural indices for eleven Schroeder Mounds subadults compared to the crural indices of the Maresh (1970) tabular data.

Figure 5 illustrates the graphic position of the seven individuals against the calculated normal for five age categories. The chronologic age with the highest indices (i.e., the most foreshortened limbs) is circa ten years of age. A line at the intersection of the two indices segregates the scores into a brachial index bias (upper left chart) or a crural index bias (lower right chart). The Schroeder Mounds individuals all fall into the upper left side of the chart, meaning that for individuals with arm and leg data, the forearm is relatively more foreshortened.

Discussion

The results indicate that the subadults of the Schroeder Mounds sample experienced some combination of disease or nutritional stress, as all had some level of forearm or foreleg foreshortening relative to modern clinical samples. The irrelevance of the presence of the specific suite of chronic pathological conditions or developmental stress to the evidence of growth stunting is not unique to this study (e.g., Temple 2008) and suggests that many factors influencing growth and development may be involved. Indeed, a consistent context of malnutrition and pathologies has been documented in other paleopathological samples suggesting that variables not quantified in this study may yet explain the role of the Late Woodland period socioeconomic circumstance (Buckley 2000; Cardoso 2005; Cook 2007; Coly 2006; Crimmens et al. 2006; Goodman and Armelagos 1988; Green and Nolan 2000; Larsen 2015; Lewis 2007; Lin et al. 2013; Mays et al. 2009; Pardo 2011; Roberts and Manchester 2007; Šlaus 2002; Temple 2007; Waldren 2009).

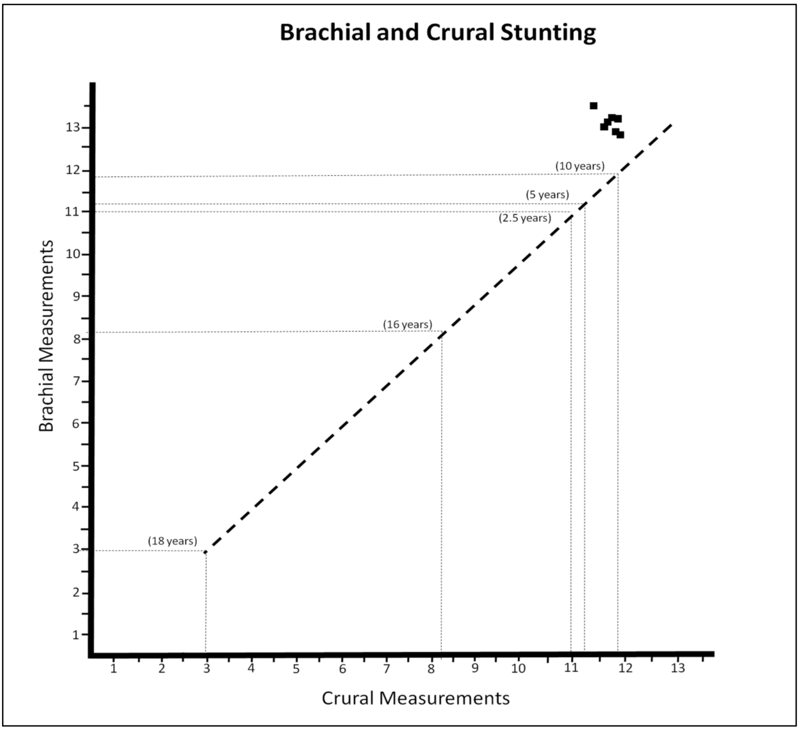

Figure 5: Chart of the brachial to crural indices. Comparative indices presented are the oldest age cohort and the subadults that generated the shortest forearm and foreleg indices. The Schroeder Mounds individuals who generated both indices indicate that both limbs display growth stunting and the brachial index is higher (i.e., more foreshortened) than the crural.

The evidence of stunting in an infant and the individuals skeletally aged as between one and two years in the Schroeder Mounds sample suggests a co-association with a poor prenatal maternal diet and/or poor quality of supplemental foods during the process of weaning. Bioarchaeological evidence of in-utero stress (e.g., Buckley 2000; Cardoso 2005; Chang et al. 2003; Goodman and Armelagos 1989; Owsley and Jantz 1985; Šlaus 2002; Thorn et al. 2013; Watson and Wall 2012), and/or poor quality supplemental foods (Grottenthaler 2005; Krishnamachari et al. 1975; Lagia et al. 2007; MacCarthy et al. 2012; Martin et al. 2014; Walker et al. 2009) has certainly been documented in other samples. The evidence in the Schroeder sample is not paleopathologically unique.

The difference between the brachial and crural departures from the calculated normal trajectory may relate to the differential growth of the human body (Harrison 1992; Martorell and Habicht 1986; Sinclair and Dangerfield 1973). Maximum appendicular growth is first attained by the lower limb and then the upper limb. It is possible that the differential seen in the Schroeder Mounds subadults reflects sufficient health and nutritional resources to achieve leg length, but a shortfall with respect to arm growth.

Socioeconomic and Physical Environment

During the Late Woodland period in the mid-continent, there were major subsistence, settlement, demographic, and sociopolitical changes moving toward maize-intensive agriculture, large nucleated settlements, and the centralized political authority that characterizes the Mississippian period (~1050-1350 AD) (Emerson and Lewis 2000; Green and Nolan 2000; Pauketat 2004). The adoption of a sedentary lifestyle and the incorporation of agriculture (and the potential of poor harvests) or starchy foods (high volume, low nutritive or caloric value) possibly contributed to negative community health responses that affected overall subadult growth and development (Mummert et al. 2011). The subsistence-settlement system of Schroeder Mounds was remote from the Mississippianization of lower west-central Illinois and apparently exhibited a forager-farmer economy with small semi-sedentary settlements (Emerson and Lewis 2000; Green and Nolan 2000; Mosher et al. 2015; Smith et al. 2016; Trader 2011). The resources, such as nuts (acorn, hickory, and groundnut) and indigenous cultivated grains (chenopod, knotweed, maygrass, etc.) were prominent food sources. These plants were incorporated into staple gardens while maize incorporation was quite slow during the Middle-Late Woodland periods in Illinois (Cook 1979; Cook 2007; Hedman and Emerson 2008; Yarnel and Black 1985). But once societies increased their reliance on maize agriculture, population density increased and diseases became more prominent. These were heavily influenced by the poor nutritional content of maize, its negative effects on dental health (e.g., dental carries [cavities], periodontal disease, etc.), and individuals living in close proximity to one another (Roberts and Manchester 2007). During the Late Woodland, the American Bottom lacks evidence of maize cultivation indicating that there was a continued reliance on small-seed crops (Cook 2007; Hedman and Emerson 2008). However, caries are present in the Schroeder Mounds sample (Lacy and Smith 2013), suggesting an economy in flux and possibly vulnerable to agricultural shortfall, which may have contributed to subadult forelimb stunting.

Pathological Conditions

The subadults in this study variably exhibited cribra orbitalia, LEH, and periostosis. Some of the subadults displayed no evidence of stress yet growth was still stunted. LEH can be caused by a wide variety of perturbations and are bioarchaeologically useful, as they are a permanent record of early childhood stress (Goodman and Armelagos 1988; Larsen 2015; Lewis 2007; Ribot and Roberts 1996; Roberts and Manchester 2007; Temple 2008), but may or may not reflect frailty. However, LEH occurs as early as one year of age in the Schroeder sample, indicating that perturbations could possibly have played a role in subadult forelimb stunting during the infancy and/or weaning periods.

The presence of multiple cases of cribra orbitalia within the fifteen-case sample suggests chronic, perhaps community-wide, subadult health issues. The causes of cribra orbitalia include anemia (dietary [iron deficiency] and/or parasite load), scurvy, and/or malnutrition (DiGangi and Moore 2012; Humphrey 2000; Mittler et al. 1994; Roberts and Manchester 2007; Yarnell and Black 1985). Although cribra orbitalia is primarily a reactive process of childhood, maternal anemia can be associated with elevated pre- and postnatal infant mortality (Blom et al. 2005). However, unhealthy bone tissue is subject to remodeling in chronic conditions and ultimate recovery (i.e., obliteration of pitting) by adulthood. The presence of an iron-deficiency could have caused the weakening of the immune system, contributing to an increased presence of acute diseases, such as heart disease and parasitic infections, ultimately causing higher mortality rates within a sample (Humphrey 2000).

Periostosis is present on only a few of the subadults. The reactive change (e.g., fine pitting, longitudinal striations, and/or plaque-like new bone formation) is an inflammatory response of the periosteum initiated by the immune system, resulting in the stimulation of osteoblasts lining the subperiosteum (e.g. Larsen 2015; Lewis and Roberts 2007; Waldren 2009). Periostosis reflects a chronic inflammation that might reflect, or be indicative of, constitutional stress, which might result in forearm or foreleg stunting.

In sum, the presence of chronic and early childhood stress in the Schroeder Mounds subadults suggests that there were a wide range of perturbations that could affect growth.

Cultural Impacts on Growth

Many aspects of culture—such as practices (e.g., weaning age, child labor, women engaged in heavy labor while pregnant, workload distributions), social organization, and implementations of activities (e.g., hygiene, medical care)—can affect the development of subadult growth (Baxter 2005; Humphrey 2000; Larsen 2015; Leonard et al. 2010; Lewis 2007; Martin et al. 2014; Scheper–Hughes 1985; Shell-Duncan and Walter 2000). For example, during the Middle to Late Woodland periods, Claassen (2002) considers the possibility of workload increase (e.g., intensified agriculture) for women to the point of marshaling young children to assist as field labor, or child caretakers. Workload may also have resulted in early infant weaning. There may also be a cultural or emotional disconnect toward small children due to high mortality or societal exclusion (i.e., personhood) (Schillaci 2011).

Conclusion

When compared to the normal growth curve, the Schroeder Mounds subadults exhibited forearm and, to a lesser extent, foreleg stunting. Although malnutrition is often cited as a primary cause of growth stunting, much clinical and bioarchaeological literature cite the contribution of chronic health problems that stress the physiology and result in a failure to thrive. A wider range of stressors than the LEH, cribra orbitalia, and periostosis quantified here apparently contribute to growth stunting, as it is present in individuals who do not exhibit any past or chronic reactive change. The fifteen individual subadult sample size is too small to assess the relative or differential importance of the pathological conditions to growth and development. Clearly, more auxiliary information is needed to contextualize the growth data. This includes the assessment of subadults from other Late Woodland period samples as well as the time periods preceding and post-dating Schroeder Mounds. Also, it would be beneficial to investigate other proxies to measure subadult growth stunting when long bone lengths are immeasurable. Future research will address the presence of growth stunting in the adult population from Schroeder Mounds (study pending). Whether or not forelimb foreshortening is exclusive to the subadult component will impact the interpretations of the dietary stability of Mississippi River Valley. The goal of the current project and future research is to generate a more cohesive picture of the Late Woodland subsistence-settlement context of Schroeder Mounds and of the greater Mississippi River Valley.

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