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Linear Enamel Hypoplasia in Permanent Dentition of Children in the Late Archaic and the Late Prehistoric River Valley

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ABSTRACT The intensification of agriculture is often correlated with an increase in physiological stress, but this relationship is not always clear and needs to be examined in biocultural context. This project compares the timing and duration of stress events of foragers (4000-3000 B.P.) with those of agriculturalists (A.D. 1000-1500) by analyzing linear enamel hypoplasia (LEH) on the permanent anterior teeth of 40 children from Late Archaic and Late Prehistoric Ohio River Valley. Scanning electron microscopy was used to create photomontages of the tooth surfaces. Prevalence, frequency, and duration of LEH were compared between samples using Fisher's exact tests and pairwise ANOVA. Results indicate that agriculturalist children endured the highest prevalence and frequency of stress events; although, forager children endured longer durations of stress events. Variation in stress experiences may be attributed to the nutritional transition to maize consumption and food storage during the Late Prehistoric period. However, a period of increased conflict, population aggregation, and political shifts from interaction with Mississippians are also discussed as contributing factors.

The intensification of agriculture often corresponds to an increase in skeletal indicators of physiological stress and growth disruption relative to hunter-gatherers in similar environments (Cohen and Armelagos, 1984; Cohen, 1989; Steckel and Rose, 2002; Larsen, 2006; Ungar et al., 2017). For example, at Dickson Mounds, Illinois, multiple indicators show increasing levels of nutritional stress and infectious disease with the rise of maize agriculture (Goodman and Armelagos, 1988; Kent 1986). However, this trend is not universal (e.g. Winterhalder and Kennett, 2006). Hutchinson and Larsen (1988) find that stress experiences among Native Americans of St. Catherines Island, Georgia increase in duration over time, despite similarities to previous agriculturalists in maize consumption. The authors argue this is likely due to disease and social changes introduced by the arrival of Spanish missionaries. Therefore, generalizations about the well-being of archaeological populations are not synonymous with their subsistence strategies. Life course hypotheses regarding response to early life stressors are dependent on accurate documentation of duration of stress episodes and the ages at which they occurred in order to better contextualize interpretations (Temple et al., 2013; Temple, 2014). Hutchinson and Larsen (1988) showed that information about stress episode duration could alter interpretations of the relationship between subsistence strategy and physiological stress.

Physiological stress during development results in disruption of enamel formation (Hillson, 1992), creating enamel defects that are permanently archived in the tooth crown. Bioarchaeologists consider these defects to be non-specific indicators of stress attributable to causes including psychological factors, fevers, malnutrition, infection, and trauma (Armelagos et al., 2009; Roberts and Manchester, 2005). While the crown of a tooth is forming, enamel matrix is secreted continuously by ameloblasts in successive layers starting at the crown of the tooth. Successive growth layers are differentiated by striae of Retzius (Hillson, 1996). Striae are temporally divided by cross-striations, which represent a circadian rhythm of growth, each accounting for 24 hours of growth (Fitzgerald, 1995; Hillson, 2005; Lacruz et al., 2012; Reid and Dean, 2006). Therefore, when cross striations are counted between striae of Retzius, the timing in days, or periodicity of the striae, can be determined. Externally, these striae correspond to circumferential structures that are visible on the surface of the tooth, known as perikymata (Antoine and Hillson, 2016; Hillson, 1996; Fitzgerald, 1995). Therefore, as enamel is laid down in successive layers, each perikyma represents a

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period of development in days, as reflected by the periodicity, or cross-striation count.

When a systemic stress event occurs, energy is diverted away from ameloblasts, causing a deficit in matrix secretion and the enamel volume, interrupting the normal distribution of perikymata (Hillson, 1992). The result is an increased distance between successive perikymata. These physiological disruptions during growth produce localized defects on the enamel surface, which can occur as pits, furrows, or planes (Hillson, 2005). Linear enamel hypoplasia (LEH) is the most recognizable and commonly reported form of enamel defect (Hillson and Bond, 1997; Ten Cate, 1994), and takes the form of a horizontal line or linear array of pits on the enamel surface (Goodman and Rose, 1990; Hillson, 1996). The width of LEH is the result of the number of affected perikymata; therefore, representing a quantification of the duration of stress events (Antoine and Hillson, 2016; Hubbard et al., 2009). The appearance of LEH is further influenced by its location on the tooth surface since perikymata are more widely spaced near the occlusal/apical surface and more densely packed at the cervix. This means that LEH near the crown cervix of an incisor, for example, will appear narrower compared to its matching defect on a canine, which will appear in the middle of the crown. Matched defects will often appear at different locations when using two different teeth due to differences in the timing of enamel development. Regardless of their locations on two or more teeth, defects that form in response to the same systemic stress are composed of the same number of striae of Retzius and perikymata (Antoine and Hillson, 2016; Hillson and Bond, 1996).

The occlusal wall of LEH represents the period during which the stress event occurred, while the cervical wall represents the period of recovery (Guatelli-Steinberg, 2008; Hillson and Bond, 1997). The association of LEH with perikymata thus correlates with the chronological development of the tooth enamel. In tooth cusps, striae of Retzius dome over each other and do not outcrop on the surface. As compared to posterior teeth, anterior teeth are the most useful to examine for LEH because more of their enamel surface is covered by perikymata (Goodman and Armelagos, 1985; Hillson and Bond, 1997; Guatelli-Steinberg et al., 2012).

This study reconstructs patterns of growth disruption of permanent teeth of subadults using incremental microstructures to examine LEH prevalence, frequency, duration, and age of occurrence among temporally distinct populations with different subsistence strategies (foraging and agricultural) within the prehistoric Ohio Valley. Linear enamel hypoplasia prevalence, frequency, and duration measure different aspects of the stress experience. Prevalence indicates the proportion of people in a sample who were affected by a physiological growth disturbance during childhood. Frequency reflects the average number of growth disruptions that any one person in the sample is likely to have experienced. Lastly, LEH duration is an indication of how long an individual was affected by a single growth disruption. In other words, LEH duration reflects the amount of time until that person began recovering from such an incident. Therefore, discordance of LEH prevalence, frequency, and stress episode duration is possible, though not always expected.

With the advent of agriculture in North America, maize became an important subsistence staple, although it varied regionally in the rate of adoption (e.g. Cassidy, 1984; Cook and Schurr, 2009; Goodman and Rose, 1984; Sciulli and Oberly, 2002). Isotopic analysis from numerous sites within the Ohio River Valley indicate rapid incorporation of maize in the diet in the Late Prehistoric period (1100 – 400 B.P.) with intensified agriculture (Greenlee, 2002). Although maize meets daily caloric requirements, it is a poor source of amino acids and protein (Spielmann and Angstadt-Leto, 1996; Whitney and Rolfes, 2011). The phytates and plant proteins in maize inhibit iron absorption, and niacin in maize binds to glucose molecules, decreasing their bioavailability (Baynes and Brothwell, 1990; MacKay et al., 2012). The nutritive value of maize is also altered during food processing further removing important minerals and fiber depending on the processing protocols (Rylander, 1994). If absorption or consumption of iron and other nutrients is low, anemia could result, leading to susceptibility of disease and infection (Dubos, 1965; Scrimshaw, 1964; 2003).

It is often assumed that maize gruel was introduced to infants around six months of age in Late Prehistoric populations, when growth needs begin to exceed the nutrients supplied in breast milk (Wright, 1997). Even though breast milk was likely still a significant component of an infant's diet during this time, maize gruel may not have been sufficient in providing supplementary nutrients. Therefore, throughout the weaning process, LEH may represent stresses initially caused by nutritional deficiency (Blakey et al., 1994).

Bone remodeling is also influenced by nutritional stresses and disease (Frost, 2003), and an increase in remodeling per unit area can indicate greater health risk (Cho and Stout, 2003). Nutritional problems are synergistically bound to the frequency of infection since ubiquitous pathogens can become increasingly virulent under the influence of decreased host resistance due to poor nutrition (Dubos, 1965; Scrimshaw, 1964; 2003). Greater remodeling rates in maize agriculturalists compared to foragers have been recorded from Lower Illinois River Valley sites and other locations (Stout, 1983; Stout and Lueck, 1995; Stout and Teitelbaum, 1976). These greater rates may reflect nutritional stress of a low protein maize diet.

In the Ohio River Valley, Perzigian et al. (1984) and

Cassidy (1984) studied stress indicators and dietary transitions, respectively, from Archaic (6000 – 3000 B.P.) to Late Prehistoric (1100 – 400 B.P.) periods. Dental caries and attrition show the greatest difference in populations through time in the Ohio Valley (Sciulli and Oberly, 2002). Maize agriculturalists exhibit higher frequencies of dental caries and increased frequencies of pathological conditions such as periapical lesions and antemortem tooth loss (Sciulli and Oberly, 2002). Although these conditions are a byproduct of age, the earlier appearance and elevated frequencies of dental caries among agriculturalists has been largely attributed to the increased consumption of dietary carbohydrates (Larsen, 2006; Selwitz et al., 2007).

Materials

The sample for this study consists of photomontages of cast replicas of the immature (i.e. incomplete enamel growth) permanent anterior dentition of 40 subadults from three archaeological assemblages: the Duff, Buffalo, and SunWatch sites (Figure 1). The histologically determined ages at death of individuals in the sample range from 2.23 – 10.06 years (Duff), 1.57 – 6.45 years (Buffalo), and 1.09 – 7.15 years (SunWatch) (calculated in Blatt, 2013). Poor preservation of subadult remains in the archaeological record in this area contributed to the limited sample size. Sites chosen for study also display a significant degree of genetic homogeneity (Sciulli, 1990; Sciulli and Oberly, 2002) thereby reducing the potential for variability in the data due to genetic factors. Therefore, we assume that any discrepancies in dental growth and development among the present samples are attributable to individual variation and/or environmental influences. In addition to the age distribution of well-preserved subadults, the three sites were selected for their regional consistency and the well-studied archaeological and biological contexts they provide.

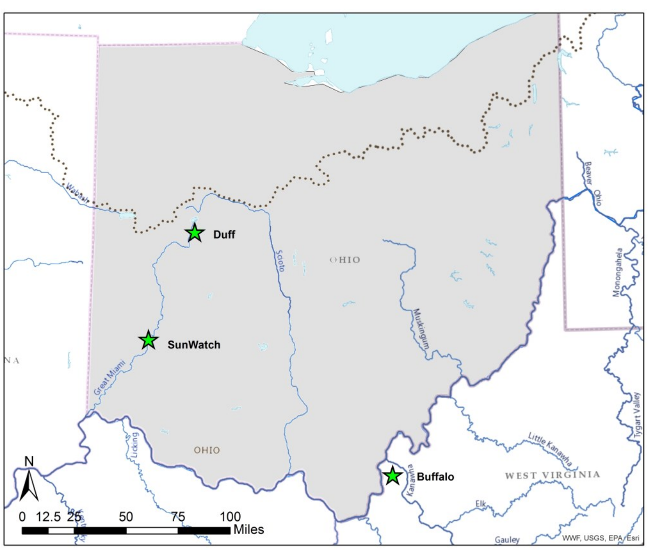

Figure 1. Map of Ohio showing the locations of the sites used in this study.

Given the body of research on the increased disease load that is often associated with the rise of maize agriculture (e.g. Cohen and Armelagos, 1984; Larsen, 2006), we first predicted that the agricultural samples in this study would exhibit a statistically significant increase in physiological stress as measured by a higher prevalence and frequency of LEH compared to the foraging sample. Second, we predicted that these stress episodes would last longer among the agriculturalists due to the assumed persistence of pathogens among a large, sedentary population. Third, we hypothesized that agriculturalist children would exhibit the earliest age of first LEH occurrence because a weaning diet supplemented by maize porridge is more likely to lead to malnutrition and systemic stress earlier in development than a foraging diet that includes a broader spectrum of foods and essential nutrients (Ungar et al., 2017). Overall, the objectives of this study were to assess change across time in the stress experiences that impacted prehistoric children of the Ohio River Valley in association with subsistence and social transitions.

A total of 31 individuals, of 40 originally sampled, had adequately developed and preserved enamel microstructures for the purposes of this study. Individuals were included if they had at least 40% of the enamel present on their incisors (Blatt, 2013). Subadults under the age of two years were excluded from analyses for this reason (Reid and Dean, 2000). Deciduous teeth were excluded since they do not consistently display perikymata. We excluded teeth with taphonomic changes and/or excessive wear to limit error in perikyma counts that would skew chronological assessment.

Duff Site (n=9)

The Duff site (22LO111), located in the mid-western area of Ohio (see Figure 1), consists of a relatively large and complete cemetery (Sciulli and Aument, 1987). Radiocarbon dates of 2,950 ± 155 years B.P. and 3100 ± 40 years B.P. from skeletal material indicate that the site was used for a short period of time during the terminal Late Archaic (ca. 3000 – 2500 B.P.) (Sciulli and Aument, 1987; Sciulli, 1990). During this time, populations lived in small scattered groups at seasonal habitation sites subsisting through hunting and gathering (Parmalee, 1969). The dietary breadth of the Duff people centered on diverse faunal assemblages, nut harvesting, wild plants, and riverine resources (Emerson et al., 2009; Parmalee, 1969). Domesticates, such as maize, were neither produced nor consumed during this period, as supported by isotopic and archaeological evidence (Stothers and Bechtel, 1987). The migratory nature of hunting and gathering populations allowed for the occupation of seasonal habitation sites, reducing the risk of resource depletion and nutritional deficiency. Sciulli and Aument (1987) report high young adult mortality, and low infant mortality among individuals at the Duff site. Warming from the Hypsithermal Period is believed to have decreased the carrying capacity in the region during the latter part of the Late Archaic, but populations appear to remain stable (Ford, 1977).

Buffalo (n=18)

The Buffalo site (46PU31) is located along the banks of the Kanawha River in Buffalo, West Virginia (see Figure 1). It was hastily excavated between 1963-1965 (Hanson, 1975), during which some burials were avoided, crushed, and displaced by bulldozers (Drooker, 2000). The site consisted of permanent settlements inhabited year-round, spanning several temporal/cultural traditions from the Archaic to the Late Prehistoric (1000-1500 A.D.) (Hanson, 1975). For the purposes of this study, only the latter period, which encompasses Fort Ancient, will be discussed since sample materials from Buffalo date from this time.

Fort Ancient is considered a regional culture of kin-structured villages that responded similarly to varying degrees of Mississippian influence (Cook, 2008; Cowan, 1986; Griffin, 1943; Henderson and Turnbow, 1987; Turnbow and Sharp, 1988). The Fort Ancient occupation of the site is seen in two overlapping villages and burials clustered in groups near house structures (Hanson, 1975). From the original excavations, very little information is reported about subsistence or social stratification at Buffalo. Many charred hickory nuts and walnuts were recovered from the site, and it appears that deer were brought back to the site for butchering. There is no reported evidence for other plants used at the site; although, numerous remains of mammals and birds were recovered (Hanson, 1975). Nevertheless, it is commonly assumed that the subsistence economy at Buffalo was associated with horticulture or less intensive agriculture (e.g. Blatt, 2013; Hanson, 1975; Sciulli and Oberly, 2002). Isotope data (^{13}C/ ^{12}C) of Mid-Late Prehistoric remains throughout the region indicates that maize was by far the most consumed food by the Fort Ancient people. Late Prehistoric Ohio Valley populations also tended to have shorter stature, a lower life expectancy, and higher infant (1-3 years) mortality than earlier hunter-gatherers (Cassidy, 1972; 1984). Such changes in mortality patterns are also likely related to the overall increase in population size and sedentism from Archaic to late prehistoric populations in the region.

SunWatch (n=13)

Contemporary with Buffalo, SunWatch (33MY57) village is the most extensively excavated and analyzed Fort Ancient site and is the type site of Middle Fort Ancient (A.D. 1200-1400) (Heilman et al., 1988; Henderson and Pollack, 2001). SunWatch is located along the Great Miami River, three miles south of Dayton, Ohio (see Figure 1). The site is comprised of a well-planned circular village, concentric circles of clustered burials, storage pit structures, and houses that were organized outwardly around a red cedar center pole (Heilman et al., 1988). This organization is thought to be part of a solar alignment system, and culminating in a stockade around the periphery (Heilman and Hoefer, 1981). Relative to hunting and gathering groups, this period is marked by increases in sedentary population size, social complexity, regional integration, and extra-regional trade (Dunnell, 1971; Drooker, 1997; Essenpreis, 1978; Griffin, 1943). Subsistence focused on a maize-intense diet. However, supplementary hunting and gathering was still employed (Rossen, 1992). Carbon isotope analysis reveals no difference between males and females in maize consumption. However, nitrogen isotope analysis shows that females ate less meat than males (Conrad, 1988). Agricultural populations tended to have shorter stature, a lower life expectancy, and high infant mortality compared with hunter gatherers (Cassidy, 1984).

Large Fort Ancient sites, like SunWatch, consumed more maize than smaller villages, but the highest carbon isotope levels were most closely associated with sites that had the highest number of Mississippian goods and structures (Cook and Schurr, 2009; Schurr and Schoeninger, 1995). Research on the degree and consistency of Mississippian interaction with Fort Ancient villages is contentious, as some authors conclude that the Fort Ancient development was necessarily stimulated by the Mississippians (Griffin, 1943; Cook, 2012), while others deny any significant influences (Pollack and Henderson, 2000).

There is significant evidence for Mississippian reach at SunWatch (Cook, 2008; 2012). Skeletal trauma and mortuary iconography that have been associated with warfare and peace keeping among Mississippian leaders, such as the inclusion of dog burials and symbolism associated with Mississippian dog soldiers, appear in one quadrant of the site, which is otherwise segmented by kin groups (Cook, 2012). Development of war leadership and presence of foreign soldiers in the village fit well with the escalating conflicts in the greater region (Milner et al., 2001). In a study of intracemetery biological variation using dental metrics, Sciulli and Cook (2016) found that SunWatch consisted of a primary Late Woodland population with some nonlocal Mississippian individuals, who were highly related to the Late Woodland population. The authors suggested that acculturation accounted for Mississippian cultural characteristics in southwestern Ohio or that gene flow, accounting for the genetic similarities between Fort Ancient and Mississippian peoples, occurred before 800 B.P. (Sciulli and Cook, 2016).

During the occupation of SunWatch, Fort Ancient sites were becoming more aggregated, as Mississippian sites became smaller (Drooker, 1997; Cook and Aubry, 2014). It is likely that these Mississippians migrated into the hinterland of Fort Ancient villages, influencing political and sociocultural transitions at villages such as SunWatch (Cook, 2012; Cook and Aubry, 2014). An influx of foreign elite leaders (as evidenced from burial inclusions and comparisons) and reshuffling of populations from patrilocal residence patterns to matrilocal could have significantly increased adult and developmental stress, nutritional stress, and pathogen load from overcrowding, as compared to other sites used in this study (Cook, 2012; Cook and Aubry, 2014).

Methods

High resolution cast replicas were made of the labial surface of anterior teeth. Photomontages were created using a FEI NOVA Nano Scanning Electron Microscope (SEM) 400 at 50 times magnification (Blatt, 2013). Replicas, histological data from sectioned teeth (discussed below), photomontages, and age estimation used in this study originate from the work of Blatt (2013).

Perikymata were identified as regularly spaced grooves running horizontally across the surface. Linear enamel hypoplasia was identified as an accentuated area in which perikymata were spaced more widely relative to those around them (Guatelli-Steinberg, 2008). Accentuation was first identified subjectively relative to adjacent perikymata. ImageJ (Rasband, 1997-2017) was then used to metrically verify the increase in width from scaled images (Figure 2).

From the photomontages available, we were unable to evaluate enamel depressions in order to identify LEH (as in King et al., 2002; Temple, 2014; 2016). Nevertheless, there was limited bias in LEH identification and perikymata counting because most individuals in the sample died prior to cervical enamel formation, which is the area most affected by tightly "packed" perikymata. Because we did not often have perikymata available to count near the cervix, we did not apply Hassett's (2012) method. However, since metric comparison of width variations among adjacent perikyma-

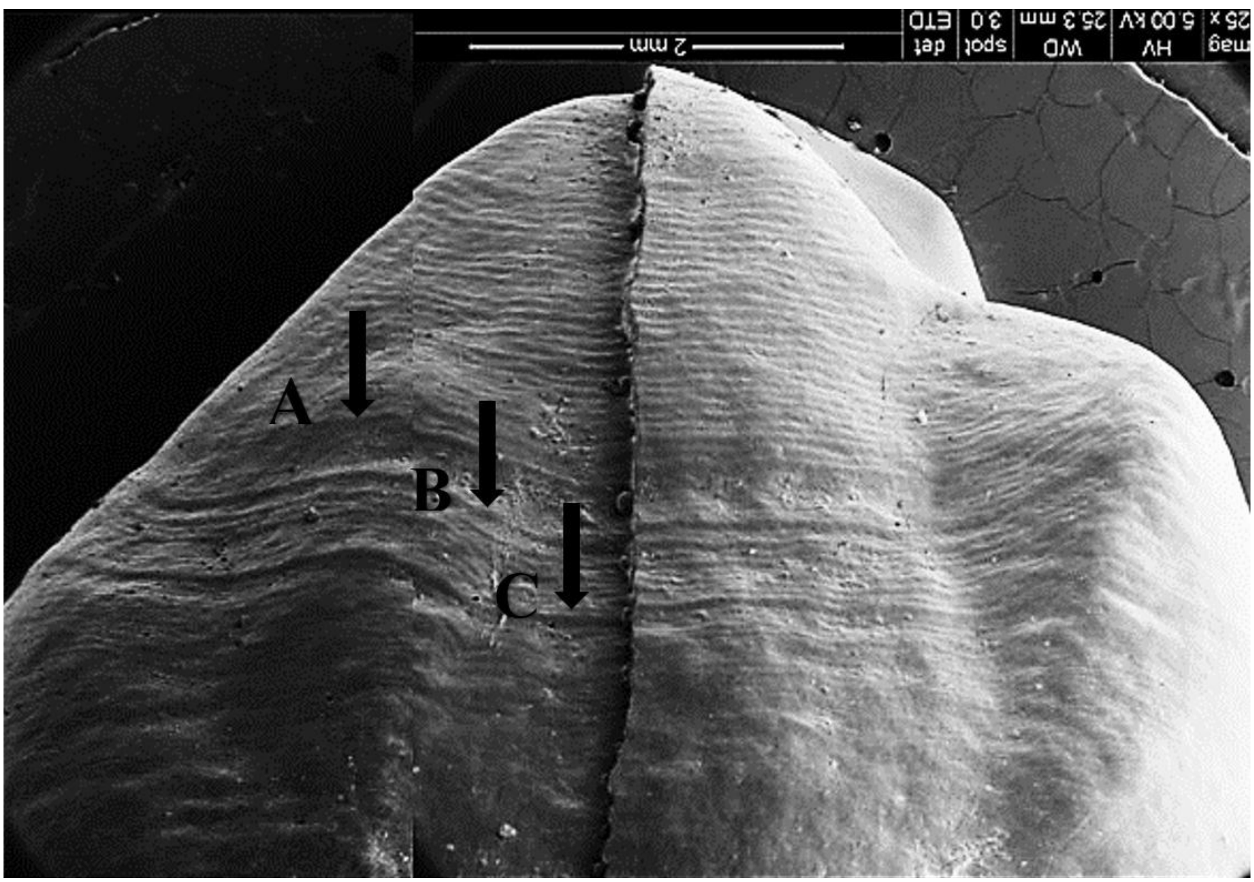

Figure 2. Photomontage example. Lower left canine of individual B6-71 from SunWatch with arrows indicating LEH (and accentuation in the horizontal perikymata). LEH A includes 6 perikymata, LEH B and C both have two perikymata each. Occlusal surface is towards the top. Modified from Blatt (2013).

ta was not performed along the entire enamel surface, LEH prevalence and frequency data represent minima for each sample.

The method of recording LEH used in this study has been applied to other sites in the study region (Martin and Sciulli, 2008; Steckel et al., 2002) and should produce comparable data. Perikymata were counted from the occlusal/apical end until the onset of each accentuation. This procedure eliminated any visual confusion thereby minimizing intra-observer error. Perikymata of each tooth were counted twice at least one week apart and the mean number of perikymata was used as the final count result (Blatt, 2013).

We matched defects between two anterior teeth from each individual in order to eliminate any defects associated with localized trauma. Defects were matched by comparing duration, interval between successive defects, and the histologically derived estimate from enamel microstructures of the age at onset for each hypoplasia on each tooth (Blatt, 2013). Frequency was calculated for each individual by counting the average number of matched LEH occurrences among the anterior teeth. Individuals with two anterior teeth with observable defects were categorized as LEH positive. To calculate prevalence, the number of LEH-positive individuals was divided by the total number of individuals with at least two observable anterior teeth and is presented as a percentage. The interval between successive defects was recorded as the number of perikymata from the beginning of one LEH to the start of the next. Subsequently, perikymata were counted within each accentuation to establish the duration of each LEH event (Hubbard et al., 2009). Duration was expressed as the number of all perikymata affected by a growth disruption.

Although Hillson and Bond (1997) argue that the duration of growth disruption should be evaluated as the number of perikymata in the occlusal wall of a defect, the total number of affected perikymata was used as an indirect indicator of stress duration since the transition between occlusal and cervical walls was often not clear. As such, stress episode duration in this study includes the periods of disruption and recovery (Guatelli-Steinberg et al., 2005). Stress duration was calculated as the total number of perikymata, as defined above, multiplied by the periodicity (Blatt, 2013). Periodicity (number of days represented by each perikyma from each population) was determined in two ways: either by direct counts of cross striations between striae of Retzius, or by measuring the length (in μm) between adjacent striae of Retzius divided by the local mean daily secretion rate (Blatt, 2013). A modal periodicity of eight days (for n = 7 teeth) was determined for the sample through histological analysis by Blatt (2013).

To calculate the ages at which stress events occurred, the total number of perikymata from the occlusal surface of each tooth to the beginning of each identified LEH was counted and multiplied by the periodicity. This total was then added to the initiation times (Reid and Dean, 2006; Blatt, 2013), representing the age at which tooth calcification begins. Subsequently, mean cuspal enamel formation time (determined by Blatt, 2013) was added, representing the time since initiation and first perikyma outcropping, for each specific tooth. The sum of these values and the developmental timing of all perikymata was then subsequently divided by 365.25 to yield age of occurrence in years. The age of occurrence of subsequent defects were calculated by adding the number of days between defects (duration plus interval) to the age of occurrence of the previous defect. Ages ranges at death (with correction factors) for all individuals in this study were previously provided through microstructural and histological analyses by Blatt (2013). It has long been agreed upon and thoroughly tested that microscopic methods provide more accurate age estimates than those using macroscopic methods (FitzGerald and Rose, 2008; Stringer et al., 1990); therefore, many of the estimations normally required for assessment of age and duration of LEH were eliminated.

Since it is unknown if the subsistence economy at Buffalo focused as intensely on maize agriculture as at SunWatch, the samples from these sites are considered separately rather than pooled. To control for possible bias in defect duration comparisons that could have been caused by amount of mineralized enamel available for observation, the samples were separated into two groups: those who died before 3.5 years, and those who died after 3.5 years. Blatt (2013) found that Ohio Valley children completed crown development for all incisors by 3.5 years (ranged 3.13 – 3.5 years). As such, groups were divided by enamel completion such that the younger subadults had at least 40% of enamel visible (Blatt, 2013). Defect prevalence for each site is not affected by this sectioning since all individuals under the age of two were excluded from analyses. Prevalence was compared between samples using a Fisher's exact test in the statistical computing environment R (R Core Team, 2013). Box plots were produced to depict ranges of stress episodes. Stress episode duration and age at first occurrence were compared between the samples using a one-way ANOVA with Tukey's HSD test for each pairwise comparison. Overall, these tested the similarities and differences in the stress experiences of hunter-gatherers relative to agriculturalists in the prehistoric Ohio Valley.

Results

Of the 14 individuals from Buffalo, 12 (85.7%) presented hypoplastic defects. Prevalence among SunWatch individuals was similar; eight of the nine (88.9%) subadults displayed at least one enamel hypoplasia while those from the Duff site exhibited a prevalence of four out of eight (50%). Frequency of LEH for the Buffalo and SunWatch sites was also similar, with 1.8 and 1.89 defects per tooth respectively. The smallest frequency was observed from Duff individuals, with an average of 1.125 defects per tooth. Notably, no more than three defects were matched between anterior teeth on any individual from any site. A summary of the prevalence and frequency results for all subadults are given in Table 1. Despite differences in prevalence, Fisher's exact tests showed that they did not differ significantly between the three sites nor between any two (Table 2).

Table 2. Results of the Fisher's Exact Tests. D = Duff; B = Buffalo; S = SunWatch.

Comparison	X^2	P
B, D, S	4.953	0.119
B, S	0.025	1.000
D, B	1.980	0.131
D, S	1.496	0.131

When individuals were pooled, the duration of stress episodes, given in days representing growth disruption and recovery, varied widely within each group (Table 3, Figure 3). The individuals from the Duff site experienced a longer average duration than those from Buffalo or SunWatch. Duff individuals endured stress episodes for an average of 45.75 days, whereas those from Buffalo and SunWatch endured an average of 34.9 and 25.22 days respectively. Tukey's HSD test suggested subadults from the SunWatch site experienced significantly shorter stress episodes than those from the Duff site (P = 0.021). There was no significant difference between Duff and Buffalo (P = 0.292) nor between SunWatch and Buffalo (P = 0.172). Conversely, when considering the average duration of LEH for each child, instead of average duration in each group, ANOVA showed no significant difference between samples (P = 0.122).

When comparing subadults between sites who died before the age of 3.5 years (see Table 1), Tukey's HSD test showed there was a significant difference in the duration of stress episodes only between Buffalo and SunWatch children (P = 0.03), due to the outlier seen in Figure 4, whose LEH lasted for 98 days. When considering those who died after the age of 3.5 years, duration of stress episodes among Duff children was significantly longer than both Buffalo (P = 0.003) and SunWatch durations (P = 0.018) (Figure 5). Duration of stress episodes between SunWatch and Buffalo children older than 3.5 were not significantly different (P = 0.822).

ANOVA indicates no significant difference in age at first occurrence between the three groups (P = 0.374). The ages at which subadults from all samples experienced their first stress episode began between 0.89 and 2.67 years. Table 3 shows the ages at which each stress episode occurred, and the duration of each event. Age ranges are given for each LEH using the standard deviation values for each tooth, from Blatt (2013). The consistency of multiple LEH occurrences within the second and third years of life among the SunWatch sample prompted an investigation of the interval between LEH. The average times between successive LEH: 115.6 days at Duff; 155.43 days at Buffalo; and 86 days at SunWatch.

Discussion

Although LEH prevalence among the Buffalo and SunWatch children was higher than in the Duff sample, this difference was not statistically significant, suggesting that a similar proportion of individuals were subjected to physiological stress, despite subsist-

Table 1. LEH prevalence and frequency for all individuals in each site

Site	Total Prevalence	Average LEH frequency	Pooled Ages		Ages < 3.5 Years		Age > 3.5 Years	
			Total Observed	Number with Defects	Total Observed	Number with Defects	Total Observed	Number with Defects
Duff	50.00	1.13	8	4	4	3	4	1
Buffalo	85.70	1.80	14	12	7	6	7	6
Sun Watch	88.90	1.89	9	8	7	6	2	2

Table 3. Age at occurrence for each LEH by site given in years, with the duration of each episode given in days. Ranges represent the possible age at which stress episode first began, where individual numbers represent the only viable age at which the episode could have begun, given the age overlap between the observed teeth. Age at death is also presented for each individual.

Site	Individual ID	Age at Death (years)	LEH A Age (years)	LEH A Duration (days)	LEH B Age (years)	LEH B Duration (days)	LEH C Age (years)	LEH C Duration (days)
Duff	B19	10.06	2.67	78	3.03 - 3.12	52	3.36 - 3.49	58
	B37	2.93	1.29	18	1.63 - 1.80	22	-	-
	B45	2.6	1.64	-	-	-	-	-
	B75A	2.93	1.68	32	1.81	58	2.07	48
Buffalo	D10-B24	2.71	2.06-2.11	24	2.31-2.37	72	-	-
	D10-B38	6.12	1.42-1.67	14	-	-	-	-
	D11-B27	2.36	1.27-1.31	28	1.56-1.58	22		
	D12-B9	3.15	2.5 - 2.62	28	3.32 - 3.63	24	-	-
	E7-B12	2.76	2.56	30	2.85	28	-	-
	E8-B18	5.06	1.01	20	1.27	32	-	-
	E8-B76	6.45	0.99 - 1.08	20	1.74	54	2.24 - 2.26	50
	E8-B82	5.06	1.98 - 2.16	14	2.36 - 2.58	24	-	-
	E9-B10	5.81	1.25 - 1.33	22	1.69 - 1.85	26	-	-
	E10-B43A	3.53	1.12 - 1.29	36	1.84	40	2.47	22
	E10-B110	2.91	1.31 - 1.47	40	-	-	-	-
	F10-B20	2.87	0.97	42	1.22	66	1.54	98
SunWatch	B3-74	2.99	1.84 - 2.00	8	-	-	-	-
	B6-71	4.16	1.92	42	2.05	18	2.19 - 2.23	20
	B6-73	2.87	1.38 - 1.47	16	1.45 - 1.57	28	1.54 - 1.65	40
	B6-80	2.67	0.89 - 1.06	8	1.12 - 1.28	24	1.51 - 1.68	42
	B10-80	2.32	1.43 - 1.58	14	-	-	-	-
	B11-76	2.65	1.98 - 2.04	14	2.04 - 2.14	28	2.29	28
	B13-72	7.15	1.56 - 1.84	36	2.39 - 2.56	44	-	-
	B14A-72	2.98	1.85 - 1.88	24	2.14 - 2.24	20	-	-

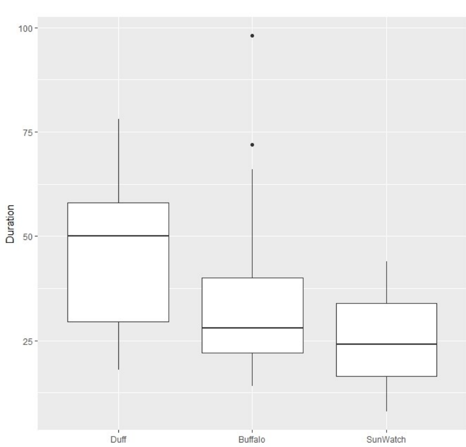

Figure 3. Stress episode duration given in days for all individuals, the whiskers indicate 95% confidence intervals.

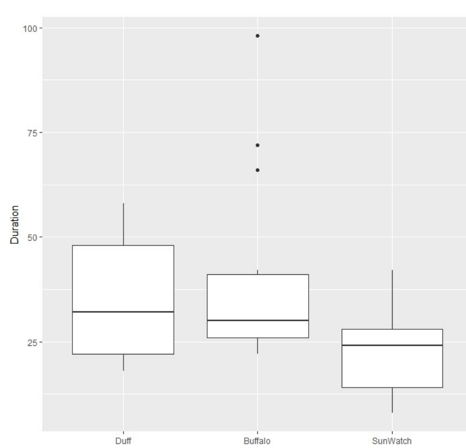

Figure 4. Stress episode duration given in days for individuals who died before the age of 3.5 years, the whiskers indicate 95% confidence intervals.

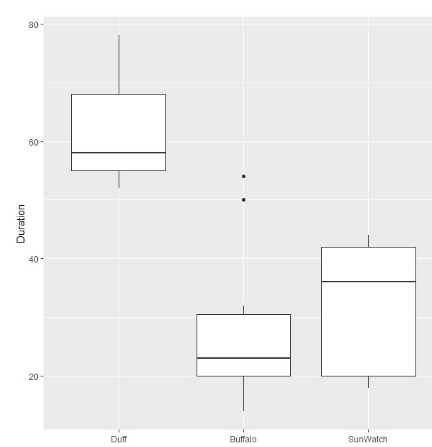

Figure 5. Stress episode duration given in days for individuals who died after the age of 3.5 years, the whiskers indicate 95% confidence intervals.

ence strategy differences and aggregation hazards in Late Prehistory. The average number of defects per tooth was lowest among the Duff sample, supporting the first hypothesis that the agricultural groups experienced a higher frequency of stress episodes. Average duration of LEH defects was significantly different between Duff and SunWatch, where Duff children experienced longer stress episodes than SunWatch children. Here, the duration analysis refutes the second hypothesis because foragers in this study endured longer stress episodes than did maize agriculturalists. These results suggest that Duff children experienced physiological stress less often than those at Buffalo or SunWatch. However, stress episodes lasted longer at Duff than at the other two sites.

Discord between LEH prevalence, frequency, and duration is seen in other studies that use LEH to examine stress differences in archaeological samples. For example, Temple et al. (2013) found that despite greater LEH frequencies among Jomon period foragers from Hokkaido, Japan, they had significantly shorter stress episode durations than Tigara Inupiat from Point Hope, Alaska. In another study, greater stress episode duration was evident in modern Inuit compared to Neandertals from Krapina, despite similar LEH prevalence within each sample (Guatelli-Steinberg et al., 2004). King et al. (2005) found significant differences in LEH prevalence between females from two historic London cemeteries, although there were no significant differences between duration or frequency of stress episode. These studies attribute the differences in stress experiences to seasonal variation in food availability and/or dietary quality between their samples.

The third hypothesis regarding a significant difference in age at first occurrence between agriculturalists and foragers was rejected. This result reflects the susceptibility of children in the first years of life to system stress, regardless of subsistence strategy. Many previous studies have linked the presence of LEH after the first year or so of life to the negative effects of weaning (e.g. Coppa et al., 1995; Corruccini et al., 1985; Ogilvie et al., 1989; Ubelaker, 1992; Webb, 1995). However, since other elements leading to enamel defects include nutritional problems, illness, or poor hygiene, weaning may not be the sole factor leading to growth arrest in enamel during the first year of life (see Blakey et al., 1994; Katzenberg et al., 1996).

Variation between prevalence, frequency, and duration may be attributed to differences in subsistence strategy, dietary breadth, and transitions in population size or Mississippian influences and migration. The dietary breadth of the Duff people (Emerson et al., 2009; Parmalee, 1969) suggests that children had access to foods with sufficient macro- and micronutrients, possibly helping to mitigate continuous nutritional inadequacies, resulting in reduced LEH frequency. However, due to a lack of food surplus and storage (Parmalee, 1969), if climate or seasonal variations occurred causing food depletion or relocation, Duff individuals may have experienced longer episodes of physiological stress. Indeed, climate warming impacted the region during the Late Archaic during the Hypsithermal Period (Ford, 1977), but detailed analysis of climatic changes is lacking in the literature. The increased frequency of stress episodes observed in both SunWatch and Buffalo children supports previous studies suggesting an increase in chronic systemic disturbances in Late Prehistoric agricultural populations (e.g. Cassidy, 1984; Cook, 1984; Danforth, 1999; Mummert et al., 2011; Larsen, 2006; Sciulli and Oberly, 2002).

It is common to also compare stature between groups as an indirect indicator of stress. Specifically, numerous archaeological remains have shown a reduction in stature and decline in overall health with the introduction of intensive agriculture (Cook, 1984; Danforth, 1999; Mummert et al., 2011; Larsen, 2006; Scuilli and Oberly, 2002; Temple, 2010). However, trends in stature reduction and the foraging-agriculture transition are not universal. Many studies have shown a decrease in juvenile stature with the rise of agriculture (e.g. Mummert et al., 2011), while others show no change, an increase, or an increase in regional variability in stature (e.g. Steckel and Rose, 2002; Temple, 2011). Sites from the Lower Illinois River Valley do not indicate adult stature changes through time or subsistence transitions, even though there is evidence of reduced juvenile stature (Cook, 1984). Children from all sites in this study have also been shown to have achieved a lower percentage of attained growth progression of femur length at each age relative to the mean attained growth achieved by the children from the Denver Growth Study and Columbus Morgue samples (Maresh, 1955; Sciulli, 1994; Sciulli and Blatt, 2008). Additionally, significant differences ($P = 0.001$) were reported between skeletal age and dental age between the children in these three sites (Blatt, 2013), indicating compromised physiological growth despite biological age.

SunWatch results also support indications of systemic early life or prenatal stresses reported from enamel defects of deciduous teeth (Martin and Sciulli, 2008). While decreased host resistance is likely to have contributed to the increase in LEH frequency in the Buffalo and SunWatch subadults, a diminished quality of diet is unlikely to be the only cause of an increase in frequency of stress episodes. Although an understanding of the extent of Mississippian influence at Fort Ancient sites, like SunWatch, is currently evolving, patterns of increased conflict and migration in the region are serious means of stress-inducing events to consider when comparing growth disruption through time.

Intensive agriculture at SunWatch allowed for population growth and sedentism, especially for the influx of Mississippian migration, which afforded ample opportunity for the introduction and perpetuation of novel pathogens (Goodman et al., 1984; Larsen, 1995). Increased maintenance of diseases and other pathogens relative to hunting and gathering groups may be a cause of the shortened intervals between successive stress episodes in the SunWatch children. In contrast to Duff individuals, the analysis of stress episode duration in this study suggests SunWatch children experienced shorter episodes of physiological stress.

There are some limitations and future explorations that should be considered within the framework of this project. First, the most evident issue is the small sample size. Juvenile remains from the archaeological record are often sparse and generally poorly preserved when compared to adult remains. It was difficult to obtain a sizeable sample, even from multiple sites. Compounding the problem, the sample was further reduced by omitting some individuals due to the presence of only one anterior tooth where at least two were needed to be considered for analysis.

Additionally, as mentioned above, enamel deposition is not linear in the permanent dentition (FitzGerald, 1995; Hillson and Bond, 1997; Reid and Dean 2000). The beginning of a hypoplastic defect is typically identified as the point where a perikyma is more widely spaced than its occlusal neighbors. Yet, the spacing between each successive perikyma can be variable through different parts of the same tooth since perikymata are packed more tightly in some areas as compared to others (Schwartz et al., 2001). In order to *accurately* calibrate the spacing between perikymata across differently packed areas, the mean distance and standard deviation would ideally be calculated based on the nearest neighbors (Hassett, 2012). However, a reliable and definitive study of dental enamel via microscopic analysis requires expensive analytical tools that are impractical in many field and laboratory situations compared. For many researchers, it is more reasonable, instead, to assess interobserver reliability of dentition that had limited variation in perikymata "packing", as in this study.

Finally, it is noteworthy that enamel hypoplasias can be observed only on those individuals who survived the stress events, and what cannot be known is if the children died during another episode, or due to some other cause. Markers of disease or deprivation in human remains represent only a fraction of the health disruptions in a population since most diseases will not leave lesions on bone, or will abate or kill their hosts before being expressed on skeletal tissue (Wood et al., 1992).

Conclusions

The results of this study indicate observable differences in LEH frequency and duration between the Duff, Buffalo, and SunWatch subadults. Our first hypothesis was confirmed; the agricultural samples reflected an increase in physiological stress through higher LEH frequencies and prevalence than those observed in the foraging sample (see Table 1). Contrary to the second hypothesis, the stress experiences of Duff children lasted longer than those of SunWatch or Buffalo, possibly due to differences in resource storage in cases of resource depletion or climate variations. In this case, SunWatch children relied on protein-deficient maize in a populated environment ripe for spreading pathogens, whereas Duff children had access to a more balanced diet in a sparsely populated environment.

An alternative explanation for the differences in the health experiences of hunter-gatherers and agriculturalists is that Late Archaic (Duff) populations did not possess the techniques, practices, or support for sick individuals. In the case of the Duff population, in which groups were initially becoming larger and less mobile, a sedentary lifestyle was probably in its early stages of development, which would have increased the propensity for pathogens to spread (Sciulli and Oberly, 2002). With that in mind, individuals inflicted with a potentially life-threatening illness may have been more likely to die in a short time, leaving skeletons, or their teeth, unmarked by acute effects of illness.

There is a trend for hunting and gathering populations in the Eastern Woodlands to exhibit fewer pathological conditions on their skeletons and teeth as compared to sedentary populations who assumedly had established techniques and support for ill people (Sciulli and Oberly, 2002; Steckel et al., 2002). On average, in the former populations, individuals with obvious effects of disease did not live as long. Conversely, in groups with well-developed care practices, like that at SunWatch, individuals would have had a better chance of surviving acute phases of disease. As such, these populations would have had longer lives (Sciulli and Oberly, 2002). Therefore, if chronic phases of diseases were to develop, they would manifest in their skeletal remains.

Expansion of this project should explore these trends by supplementing this analysis with the inclusion of adult skeletal materials to assess health within the life course approach (Agarwal, 2016). Ideally, the childhood stress experiences archived in LEH should be examined in individuals who survived childhood in order to assess potential links between childhood stress and health in later life. A greater understanding of the long-term impact of subsistence and social transitions in the Ohio River Valley would also benefit from comparison of adult attained stature with frequency of LEH observed in adults. The assumption being that increased LEH is correlated with having shorter adult stature and shorter lives as the result of childhood stress.

Temple (2014) assessed future risk of stress from early life stress. Such patterns have been demonstrated in recent studies (Amoroso et al., 2014; Temple, 2014; Watts, 2013) but samples from North America have not yet been applied to this model to aid in this complicated discourse. Nevertheless, the study of stress patterns in children is important for narrating the life course of young shortened lives.

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REFERENCES

Agarwal, S.C. (2016). Bone morphologies and histories: Life course approaches in bioarchaeology. *Yearbook of Physical Anthropology*, *American Journal of Physical Anthropology,* 159, S130-S149.

Amoroso, A., Garcia, S.J., & Cardoso, H.F.V. (2014). Age at death and linear enamel hypoplasias: Testing the effects of childhood stress and adult socioeconomic circumstances in premature mortality. *American Journal of Human Biology*, 26, 461-468.

Antoine, D., & Hillson, S. (2016). Enamel structure and properties. In: J.D. Irish, G.R. Scott (Eds.), *A Companion to Dental Anthropology* (pp. 223-243). West Sussex: Wiley Blackwell.

Armelagos, G.J., Goodman, A.H., Harper, K.N., & Blakey, M.L. (2009). Enamel hypoplasia and early mortality: Bioarchaeological support for the Barker hypothesis. *Evolutionary Anthropology*, 18, 261-271.

Baynes, R.D. & Bothwell, T.H. (1990). Iron deficiency. *Annual Review of Nutrition*, 10, 133-148.

Blakey, M.L., Leslie, T.E., & Reidy, J.P. (1994). Frequency and chronological distribution of dental enamel hypoplasia in enslaved African Americans: A test of the weaning hypothesis. *American Journal of Physical Anthropology,* 95, 371-383.

Blatt, S.H. (2013). From the mouths of babes: Using incremental enamel microstructures to evaluate the applicability of the Morrees method of dental formation to the estimation of age of Prehistoric Native American children. Dissertation. The Ohio State University.

Cassidy, C.M. (1984). Skeletal evidence for Prehistoric subsistence adaptation in the Central Ohio River Valley. In M.N. Cohen, G.J. Armelagos (Eds.). *Paleopathology at the Origins of Agriculture* (pp. 307 -345). Orlando: Academic Press.

Cho, H., & Stout, S.D. (2003). Bone remodeling and age-associated bone loss in the past: a histomorphometric analysis of the Imperial Roman skeletal population of Isola Sacra. In: S.C. Agarwal, S.D. Stout (Eds.) *Bone Loss and Osteoporosis: An Anthropological Perspective* (pp. 207-228). New York, NY: Kluwer Academic Plenum.

Cohen, M.N., Armelagos, G.J. (1984). *Paleopathology at the Origins of Agriculture*. Orlando: Academic Press.

Conrad, A. (1988). Analysis in dietary reconstruction. In J.M. Heilman, M.C. Lileas, C.A. Turnbow, (Eds.). *A History of 17 Years of Excavation and Reconstruction - A Chronicle of 12th Century Human Values and the Built Environment, Vol I* (p. 112-156). Dayton Museum of Natural History.

Cook, R.A. (2008). *SunWatch: Fort Ancient Development in the Mississippian World*. University of Alabama Press, Tuscaloosa.

Cook, R.A. (2012). Mississippian dimensions of Fort Ancient mortuary program: The development of authority and spatial grammar at SunWatch village. In: L.P. Sullivan, R.C. Mainfort (Eds.). *Mississippian Mortuary Practices: Beyond Hierarchy and the Representationist Perspective*. (pp. 113-127) University of Florida Press.

Cook, R.A., & Aubry, B.S. (2014). Aggregation, interregional interaction, and postmarital residence patterning: A study of biological variation in the Late Prehistoric Middle Ohio Valley. *American Journal of Physical Anthropology*, 154, 270-278.

Cook, R.A., & Schurr, M.R. (2009). Eating between the lines; Mississippian migration and stable carbon isotope variation in Fort Ancient populations. *American Anthropologist*, 111, 344-359.

Coppa, A., Cucina, A., Chiarelli, B., Calderon, F.L., &

Mancinelli, D. (1995). Dental anthropology and paleodemography of the Precolumbian populations of Hispaniola from the third millennium B.C. to the Spanish conquest. *Human Evolution,* **10**,153-167.

Corruccini, R.S., Handler, J.S., & Jacobi, K.P. (1985). Chronological distribution of enamel hypoplasias and weaning in a Caribbean slave population. *Human Biology,* 57, 699-711.

Cowan, C.W. (1986). *Fort Ancient Chronology and Settlement Evaluation in the Great Miami Valley*. 2 Volumes. Unpublished manuscript on file, Ohio Historic Preservation Office, Columbus, OH.

Drooker, P. (1997). The view from Madisonville: Prehistoric western Fort Ancient interaction patterns. *Memoirs of the Museum of Anthropology No. 31*, University of Michigan, Ann Arbor.

Drooker, P. (2000). Eastern Fort Ancient Mortuary Patterns: Preliminary results from Buffalo, WV. SAA Poster, Philadelphia.

Dubos, R. (1965). *Mankind Adapting*. Yale University Press, New Haven.

Dunnell, R.C. (1971). *Systematics in Prehistory*. New York: The Free Press.

Emerson, T.E., McElrath, D.L., & Fortier, A.C. (2009). *Archaic Societies: Diversity and Complexity Across the Midcontinent*. State University of New York Press, Albany, New York.

Essenpreis, P. (1978). Fort Ancient settlement: Differential response as Mississippian--Late Woodland interface. In: B. Smith (Ed.). *Mississippian Settlement Patterns* (p.141-167). New York: Academic Press.

FitzGerald, C.M. (1995). Tooth crown formation and the variation of enamel microstructural growth markers in modern humans. PhD dissertation. University of Cambridge.

FitzGerald, C.M. & Rose, J.C. (2008). Reading between the lines: dental development and subadult age assessment using the microstructural growth markers of teeth. In: M.A. Katzenberg, S.R. Saunders (Eds.). *Biological Anthropology of the Human Skeleton*. Hoboken, N.J.: John Wiley & Sons.

Ford, R.I. (1977). *Systematic Research Collections in Anthropology: An Irreplaceable National Resource.* Cambridge: Peabody Museum, Harvard University.

Frost, H.M. (2003). On changing views about age-related bone loss. In: S.C. Agarwal, S.D. Stout (Eds.) *Bone Loss and Osteoporosis: An Anthropological Perspective* (pp. 19-31). New York, NY: Kluwer Academic Press.

Goodman, A.H., & Armelagos, G.J. (1985). Factors affecting the distribution of enamel hypoplasias within the human permanent dentition. *American Journal of Physical Anthropology,* 68, 479-493.

Goodman, A.H., & Armelagos, G.J. (1988). Childhood Stress and Decreased Longevity in a Prehistoric Population. *American Anthropologist,* 90, 936-944.

Goodman. A.H., & Rose, J.C. (1990). Assessment of systemic physiological perturbation from dental enamel hypoplasias and associated histological structures. *Yearbook of Physical Anthropology,* 33, 59 -110.

Goodman, A.H., Lallo, J., Armelagos, G.J., & Rose, J.C. (1984). Health changes at Dickson Mounds, Illinois (A. D. 950-1300). In: M.N. Cohen, G.J. Armelagos (Eds.). *Paleopathology at the Origins of Agriculture* (pp. 271-305). Orlando: Academic Press.

Griffin, J. (1943). *The Fort Ancient Aspect: Its Cultural and Chronological Position in Mississippi Valley Archaeology*. Ann Arbor: University of Michigan Press.

Greenlee, D.M. (2002). *Accounting for Subsistence Variation among Maize Farmers in Ohio Valley Prehistory*. Unpublished Ph.D. dissertation. Department of Anthropology, University of Washington, Seattle.

Guatelli-Steinberg, D. (2008). Using perikymata to estimate duration of growth disruption in fossil hominin teeth: Issues of methodology and interpretation. In: J.D. Irish, G.C. Nelson (Eds.). *Technique and Application in Dental Anthropology* (pp. 71 -86). Cambridge University Press, Cambridge.

Guatelli-Steinberg, D., Ferrell, R.J., & Spence, J. (2012). Linear enamel hypoplasia as an indicator of physiological stress in Great Apes: Reviewing the evidence in light of enamel growth variation. *American Journal of Physical Anthropology*, 148, 191-204.

Guatelli-Steinberg, D., Larsen, C.S., & Hutchinson, D.L. (2004). Prevalence and duration of linear enamel hypoplasia: A comparative study of Neandertals and Inuit foragers. *American Journal of Physical Anthropology*, 47, 65-84.

Guatelli-Steinberg, D., Reid, D.J., Bishop, T.A., & Larsen, C.S. (2005). Anterior tooth growth periods in Neandertals were comparable to those of modern humans. *PNAS,* 102, 14197-14202.

Hanson, L.H. Jr. (1975). The Buffalo Site: A Late 17th Century Indian Village Site in Putnam County, West Virginia. *Report of Archaeological Investigations, no. 5*. Morgantown: East Virginia Geological & Economic Survey.

Hassett, B. (2012). Evaluating sources of variation in the identification of linear hypoplastic defects of enamel: A new quantified method. *Journal of Archaeological Science*, 39, 560-565.

Heilman, J., Lileas, M., & Turnbow, C. (Eds.). (1988). *A History of 17 Years of Excavation and Reconstruction - A Chronicle of the 12th Century Human Values and the Built Environment.* Dayton: Dayton Museum of Natural History.

Heilman, J., & Hoefer, R. (1981). *Astrological Align-*

ments in a Fort Ancient Settlement at the Incinerator Site in Dayton, Ohio. Philadelphia: Society for American Archaeology.
Henderson, A., & Pollack, D. (2001). Fort Ancient. In P.N. Peregrine, M. Ember (Eds.). *Encyclopedia of Prehistory, vol 6* (pp. 174-194). New York: Kluwer Academic/Plenum Publishers.
Henderson, A., & Turnbow, C.A. (1987). Fort Ancient developments in Northeastern Kentucky. In: D. Pollack (Ed.) *Current Archaeological Research in Kentcuck, Volume I*, (pp. 205-224). Frankfort, KY, Kentucky Heritage Council.
Hillson, S., & Bond, S. (1997). Relationship of enamel hypoplasia to the pattern of tooth crown growth: A discussion. *American Journal of Physical Anthropology*, 104, 89-103.
Hubbard, A., Guatelli-Steinberg, D., & Sciulli, P.W. (2009). Under Restrictive Conditions, can the widths of linear enamel hypoplasias be used as relative indicators of stress episode duration? *American Journal of Physical Anthropology*, 138, 177-189.
Hutchinson, D.L., & Larsen, C.S. (1988). Determination of stress episode duration from linear enamel hypoplasias: A case study from St. Catherines Island, Georgia. *Human Biology*, 60, 93-110.
Katzenberg, M.A., Herring, D.A., & Saunders, S.R. (1996). Weaning and infant mortality: evaluating the skeletal evidence. *Yearbook of Physical Anthropology*, 39, 177-199.
Kent, S. (1986). The Influence of Sedentism and Aggregation on Porotic Hyperostosis and Anaemia: A Case Study. *Man,* 21, 605-636.
King, T., Hillson, S., & Humphrey, L.T. (2002). A detailed study of enamel hypoplasia in a post-medieval adolescent of known age and sex. *Archives of Oral Biology*, 47, 29-39.
King, T., Humphrey, L.T., & Hillson, S. (2005). Linear hypoplasias as indicators of systemic physiological stress: Evidence from two known age-at-death and sex populations from postmedieval London. *American Journal of Physical Anthropology,* 128, 547-559.
Lacruz, R.S., Hacia, G.J., Cromage, T.G., Boyde, A., Lei, Y., Xu, Y., Miller, J.D., Paine, M.L., Snead, M.L. (2012). The circadian clock modulates enamel development. *Journal of Biological Rhythms*, 27, 237-245.
Larsen, C.S. (1995). Biological changes in human populations with agriculture. *Annual Review of Anthropology,* 24, 185-213.
Larsen, C.S. (2006). The agricultural revolution as environmental catastrophe: Implications for health and lifestyle in the Holocene. *Quaternary International,* 150, 12-20.
Mackay, D., Hathcock, J., & Guameri, E., (2012). Niacin: chemical forms, bioavailability, and health effects. *Nutrition Reviews,* 70, 357-366.
Maresh, M. (1955). Linear growth of long bones of extremities from infancy through adolescence. *American Journal of Diseases of Children*, 89, 725-742.
Martin, S.A., & Sciulli, P.W. (2008). Enamel defects in the deciduous dentition of the SunWatch (33MY57) skeletal sample. *American Journal of Physical Anthropology,* 135, 150.
Milner, G.R., Anderson, D.G., & Smith, M.T. (2001). The distribution of Eastern Woodlands peoples at the prehistoric and historic interface. In: D. Brose, C.W. Cowan, R.C. Mainfort (Eds.) *Societies in Eclipse: Archaeology of the Eastern Woodlands Indians, A.D. 1400-1700* (pp. 9-19). Washington, DC, Smithsonian Institution Press.
Mummert, A., Esche, E., Robinson, J., & Armelagos, G.J. (2011). Stature and robusticity during the agricultural transition: Evidence from the bioarchaeological record. *Economics and Human Biology,* 9, 284-301.
Ogilvie, M.D., Curran, B.K., & Trinkaus, E. (1989). Incidence and patterning of dental enamel hypoplasia among the Neandertals. *American Journal of Physical Anthropology,* 79, 25-41.
Parmalee, P.W. (1969). Animal remains from the Archaic, Riverton, Swan, Island, and Robeson Hills sites, Illinois. In: H.D. Whinters (Ed.). *The Riverton Culture*. (pp. 104-113). Springfield: Illinois State Museum and Illinois State Archaeological Survey.
Perzigian, A.J., Tench, P.A., & Braun, D.J. (1984). Prehistoric health in the Ohio River Valley. In M.N. Cohen, G.J. Armelagos (Eds.). *Paleopathology at the Origins of Agriculture* (pp. 347-366). Orlando: Academic Press.
Pollack, D., & Henderson, A.G. (2000). Insights into Fort Ancient culture change: A view from south of the Ohio River. In: R.A. Genheimer (Ed.). *Cultures Before Contact: The Late Prehistory of Ohio and Surrounding Regions* (pp. 194-227). Columbus: Ohio Archaeological Council.
R Core Team. (2013). R: A language and environment for statistical computing. *R Foundation for Statistical Computing*. Vienna, Austria. URL: http://www.R-project.org/.
Rasband, W.S. (1997-2017). *ImageJ*. Bethesda, MD: US National Institutes of Health.
Reid, D.J., & Dean, M.C. (2000). Brief Communication: The timing of linear hypoplasias on human anterior teeth. *American Journal of Physical Anthropology,* 113, 135-139.
Reid, D.J., & Dean, M.C. (2006). Variation in modern human enamel formation times. *Journal of Human Evolution,* 50, 329-346.
Roberts, C.A., & Manchester, K. (2005). *The Archaeolo-*

gy of Disease. Ithaca, NY: Cornell University Press.
Rossen, J. (1992). Archaeological contexts and associations: the Lextran archaeobotanical collection. In D. Pollack, A.G. Henderson (Eds.). *Current Archaeological Research in Kentucky: Volume II* (pp. 223-250). Frankfurt: Kentucky Heritage Council.
Rylander, K.A. (1994). Corn preparation among the Basketmaker Anasazi: a scanning electron microscope study of *Zea mays* remains from coprolites. In K.D. Sobolik (Ed.). *Paleonutrition: The Diet and Health of Prehistoric Americans* (pp. 115-133). Carbondale, IL: Southern Illinois University at Carbondale.
Schurr, M.R., & Schoeninger, M.J. (1995). Associations between agricultural intensification and social complexity: An example from the prehistoric Ohio Valley. *Journal of Anthropological Archaeology*, 14, 315-349.
Sciulli, P.W. (1990). Cranial metric and non-metric trait variation and biological differentiation in terminal Late Archaic populations of Ohio: The Duff site. *American Journal of Physical Anthropology,* 82, 19-29.
Sciulli, P.W. (1994). Standardization of long bone growth in children. *International Journal of Osteoarchaeology*, 4, 257-259.
Sciulli, P.W., & Aument, B.W. (1987). Paleodemography of the Duff Site (33LO111), Logan County, Ohio. *Midcontinental Journal of Archaeology,* 12, 117-144.
Sciulli, P.W., & Blatt, S.H. (2008). Evaluation of juvenile stature and body mass prediction. *American Journal of Physical Anthropology*, 136, 387-393.
Sciulli, P.W., & Cook, R.A. (2016). Intracemetery biological variation at the Fort Ancient SunWatch village. *American Journal of Physical Anthropology*, 160, 719-728.
Sciulli, P.W., & Oberly, J. (2002). Native Americans in eastern North America: The southern Great Lakes and upper Ohio Valley. In R.H. Steckel, J.C. Rose (Eds.). *The Backbone of History: Health and Nutrition in the Western Hemisphere* (pp. 440-480). Cambridge: Cambridge University Press.
Scrimshaw, N. (1964). Ecological factors in nutritional disease. *American Journal of Clinical Nutrition,* 14, 112-122.
Scrimshaw, N. (2003). Historical concepts of interactions, synergism, and antagonism between nutrition and infection. *The Journal of Nutrition,* 133, 316S-312S.
Selwitz, R.H., Ismail, A.I., & Pitts, N.B. 2007. Dental caries. *The Lancet,* 369, 51-59.
Spielmann, K.A., & Angstadt-Leto, E. (1996). Hunting, gathering and health in the prehistoric Southwest. In J. Tainter, B.B. Tainter (Eds.). *Evolving complexity and environmental risk in the prehistoric Southwest, Santa Fe Institute studies in complexity*. (pp. 79-106). Vol 24. Boston, MA: Addison-Wesley.
Steckel, R.H., & Rose, J.C. (2002). *The Backbone of History: Health and Nutrition in the Western Hemisphere*. Cambridge: Cambridge University Press.
Steckel, R.H., Sciulli, P.W., & Rose, J.C. (2002). A health index from skeletal remains. In R.H. Steckel, J.C. Rose (Eds.). *The Backbone of History: Health and Nutrition in the Western Hemisphere* (pp. 61-93). Cambridge: Cambridge University Press.
Stothers, D.M., & Bechtel, S. (1987). Stable carbon isotope analysis: An inter-regional perspective. *Archaeology of Eastern North America*, 15, 137-154.
Stout, S.D. (1983). The application histomorphology of human cortical bone. *Calcified Tissue International*, 34, 337-342.
Stout, S.D., & Lueck, R. (1995). Bone remodeling rates and skeletal maturation in three archaeological skeletal populations. *American Journal of Physical Anthropology*, 98, 161-171.
Stout, S.D., & Teitelbaum, S.L. (1976). Histomorphometric determination of formation rates of archaeological bone. *Calcified Tissue Research*, 21, 163-169.
Stringer, C.B. Dean, M.C., & Martin, M.C. (1990). A comparative study of cranial and dental development within a recent British sample and among Neandertals. In: C.J. De Rousseau (Ed.). *Pimate Life History and Evolution* (pp. 115-152). New York: Wiley-Liss.
Temple, D. (2010). Patterns of systemic stress during the agricultural transition in prehistoric Japan. *American Journal of Physical Anthropology*, 142, 112-124.
Temple, D. (2011). Evolution of postcranial morphology during the agricultural transition in prehistoric Japan. In: J.T. Stock, R. Pinhasi (Eds.) *Human Bioarchaeology of the Agricultural Transition* (pp. 235-262). New York: Wiley Blackwell.
Temple, D. (2014). Plasticity and constrain in response to early-life stressors among late/final Jomon period foragers from Japan: Evidence for life history trade-offs from incremental Microstructures of enamel. *American Journal of Physical Anthropology,* 155, 537-545.
Temple, D., McGroarty, J.N., Guatelli-Steinberg, D., Nakatsukasa, M., & Matsumura, H. (2013). A comparative study of stress episode prevalence and duration among Jomon Period foragers from Hokkaido. *American Journal of Physical Anthropology,* 152, 230-238.
Ten Cate, N. (1994). *Oral histology: development, structure, and function, 4th ed.* St Louis: CV Mosby.
Turnbow, C., & Sharp, W.E. (1988). Muir: An early Fort Ancient site near the Inner Bluegrass. *Archaeological Report*, 165.

Ubelaker, D.H. (1992). Enamel hypoplasia in ancient Ecuador. In A.H. Goodman, L.L. Capasso (Eds.). *Recent Contributions of the Study of Enamel Developmental Defects* (pp. 207-217). Journal of Paleopathology, Monographic Publications, No. 2.

Ungar, P.S., Crittenden, A.N., & Rose, J.C. (2017). Toddlers in transition: Linear enamel hypoplasias in the Hadza of Tanzania. *International Journal of Osteoarchaeology*, 27, 638-649.

Watts, R. (2013). Childhood development and adult longevity in an archaeological population from Barton-upon-Humber, Lincolnshire, England. *International Journal of Paleopathology*, 3, 95-104.

Webb, S. (1995). *Paleopathology of Aboriginal Australians: Health and Disease across a Hunter-Gatherer Continent*. Cambridge, UK: Cambridge University Press.

Whitney, E.N., & Rolfes, S.R. (2011). *Understanding Nutrition, Twelfth Edition*. Belmont, CA: Cengage Learning.

Winterhalder, B., & Kennett, D.J. (2006). Behavioral ecology and the transition from hunting and gathering to agriculture. In D.J. Kennett, B. Winterhalder (Eds.). *Behavioral Ecology and the Transition to Agriculture* (pp. 1-21). Berkeley: University of California Press.

Wood, J.W., Milner, G.R., Harpending, H.C., & Weiss, K.M. (1992). The osteological paradox: Problems of inferring prehistoric health from skeletal samples. *Current Anthropology*, 33, 343-370.

Wright, L.E. (1997). Intertooth patterns of hypoplasia expression: Implication for childhood health in the Classic Maya collapse. *American Journal of Physical Anthropology,* 102, 233-247.

Deciduous Molar Morphology from the Neolithic Caves of the Meuse River Basin, Belgium

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ABSTRACT The karstic caves of the Meuse River Basin in Belgium preserve nearly 200 collective burials dating to the late Neolithic period. Among these, the cave burials of Hastière Caverne M, Sclaigneaux, Bois Madame and Maurenne Caverne de la Cave are represented by numerous individuals and radiocarbon dated to circa 4,635 to 3,830 years B.P. Dental casts from mandibular and maxillary deciduous molars are scored using multiple methods to provide a regional overview of the prevalence and expression of deciduous molar crown traits, and to compare frequencies between cave burial sites with a focus on temporal differentiation. Carabelli's trait varies from a small pit to a full cusp, the largest of which are found at Hastière Caverne M. The hypoconulid ranges from moderately large to very large. A metaconulid is absent or small. Although the results are contingent on idiosyncratic preservation, differences in the frequencies of expression of Carabelli's trait, a pronounced hypoconulid, and the presence of a metaconule and protostylid separate the earlier cave burial at Hastière Caverne M from the final/late Neolithic sites of Sclaigneaux and Bois Madame.

There are nearly 200 karstic caves of the Meuse River Basin of Belgium that preserve collective burials dating to the late Neolithic (Semal et al., 1999; Toussaint et al., 2001; Toussaint, 2007; Polet, 2011). Since habitation sites are rare, these funerary caves and rockshelters provide the principal source of information about these prehistoric farmers of the late Neolithic and the transition to the Bronze Age (Toussaint, 2007; Polet, 2011). The mortuary practices of Neolithic peoples from this region vary considerably. Some tombs contain a single burial, whereas others include two or more individuals (Toussaint et al., 2001), although the great majority are collective burials (Polet, 2011). The bones of multiple individuals are comingled in some caves. Burials are rarely found in full articulation, except in cases where single individuals are interred (Toussaint, 2007). At some caves, there is regrouping of bones into elements, such as circles of crania and bundles of long bones (Toussaint, 2007). Some individuals are completely macerated as evidenced by flint tool use (Polet, 2011), whereas others are cremated remains (Toussaint, 2007). At Bois Madame, a site in the Burnot Valley (Figure 1), it is unclear whether individuals were buried as the bones are found in an unordered manner (Dumbruch, 2003).

There may be several explanations to account for commingling within the collective burials, including the actions of burrowing and scavenging animals, geological or hydrological effects, recent human activity from grave robbers and cave explorers, or the intentional manipulation of the remains by those who deposited the deceased. Intentional manipulation may have several motivations, including burial rites, secondary reburial and creating space for additional bodies (Dumbruch, 2003; Toussaint, 2007).

About 40% of nearly 600 individuals excavated from 34 sites along the Meuse river system are subadults (Toussaint et al., 2001; Toussaint, 2007). At Bois Madame nearly a third of the individuals (33%) are identified as children (Dumbruch, 2003, 2007). More recent excavations with improved techniques are able to capture additional subadult remains, raising the proportion of children to 50% (Toussaint, 2007).

Four cave sites contain numerous subadult remains, including Hastière Caverne M, Sclaigneaux, Bois Madame and Maurenne Caverne de la Cave,

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radiocarbon dated to circa 4,635 to 3,830 years B.P. Two of the four burials are from Hastière rockshelter and include Hastière Caverne M and Maurenne Caverne de la Cave (see Figure 1). Hastière Caverne M has been radiocarbon dated to 4,345 ± 60 (AMS OxA-6558; Bronk-Ramsey et al., 2002) and can be considered early/late Neolithic.

Both Sclaigneaux and Bois Madame can be considered final/late Neolithic. The collective burial at Sclaigneaux cave is dated to 4,155 ± 35 (Paepe, 2007). Bois Madame is one of the latest sites in the sample, and the two dates obtained, 4,075 ± 38 (AMS OxA 10831) and 3,910 ± 40 (AMS OxA 10830), suggest the cave was in use during a relatively narrow time frame (Dumbruch, 2003, 2007; Toussaint, 2007).

Maurenne Caverne de la Cave from the Hastière rockshelter is associated with four dates spanning ~800 years, including 4,635 ± 45 (AMS OxA-9025), which is considered middle Neolithic (Toussaint, 2007) 4,160 ± 45 (AMS OxA-9026), 3,950 ± 70 (Lv-1483) and 3,830 ± 90 (Lv-1482), all of which are final/late Neolithic (Bronk-Ramsey et al., 2002; Toussaint, 2007). Since Maurenne Caverne de la Cave includes such a wide range of radiocarbon dates, it cannot necessarily be considered "early" or "final" late Neolithic.

Given the disparate funerary contexts that exist at Neolithic Belgian sites, the number of deciduous molars, and the high heritability of dental morphology (Turner et al., 1991; Scott and Irish, 1997, 2017; Irish, 2006; Pilloud and Larsen, 2011; Paul and Stojanowski, 2015, 2017; Pilloud et al., 2016; Scott et al., 2018), it is possible that differences in dental remains from each cave burial will parallel the chronological distinctions between sites (Bronk-Ramsey et al., 2002; Paepe, 2007; Toussaint, 2007). Previous studies of the osteological remains have concentrated on dental microwear, isotopic signatures, stature estimation, pathological conditions, and funerary ritual (Semal et al., 1999; García-Martin, 2000; Orban et al., 2000; Toussaint et al., 2001; Toussaint, 2007; Polet, 2011). The expression of nonmetric deciduous dental traits from these cave burials has not been previously explored. The aim of the study is to provide a regional review of the incidence and expression of crown traits on the maxillary and mandibular deciduous molars, and to examine the frequencies of traits across cave burials with respect to temporal variation.

On the basis of chronology, we expect the early/late Neolithic site of Hastière Caverne M to be distinct from the final/late Neolithic sites of Sclaigneaux and Bois Madame. We anticipate Maurenne Caverne de la Cave to present the most variation in dental morphology given its relatively broad time frame. Ecogeography may also explain the results; the two cave burials from Hastière rockshelter (Hastière Carverne M and Maurenne Caverne de la Cave) may resemble each other and differ from Sclaigneaux and Bois Madame (Figure 1).

Figure 1. Map of Belgium shows the location of Hastière rockshelter (Hastière Caverne M and Maurenne Caverne de la Cave), Bois Madame and Sclaigneaux. Sclaigneaux is approximately 35 km northeast whereas Bois Madame is circa 15 km north of Hastière rockshelter (drawing: ADIA ©).

Materials

Deciduous molars were examined from Hastière Caverne M, Sclaigneaux, Bois Madame and Maurenne Caverne de la Cave for a total of 27 individuals (Table 1). These gnathic remains are isolated such that each fragmentary molar and adjoining alveolus can be considered the sole remains from a given individual. Although there are hundreds of isolated teeth, only *in situ* deciduous molars were considered. The stages (1-8) created by Smith (1983, 1984) were used to characterize the wear on the deciduous molars (Tables 2-5).

Table 1. Neolithic samples

Cave burial	Maxillae	Mandibles	Individuals
Hastière Caverne M	3	2	5
Sclaigneaux	8	1	9
Bois Madame	2	4	6
Maurenne Caverne de la Cave	5	2	7
Total	18	9	27

Table 2. Preservation and wear at Hastière Caverne M, an early/late Neolithic cave burial

Identifier	Preservation	Dental wear (Smith, 1984)
Hastière 38	Nearly complete maxilla extending from the left unerupted crown of M^1 to the empty M^1 crypt on the right	dm^1 = stage 4; dm^2 = stage 3
Hastière 38[1]	Right maxillary alveolar fragment with dm^1 and dm^2	dm^1 = stage 4; dm^2 = stage 3
Hastière 39	Small maxillary alveolar fragment with dm^1 and dm^2	dm^1 = stage 3; dm^2 = stage 2
Hastière 18	Mandibular corpus extending from the left ramus base to the right dm_1; only the left dm_1 and dm_2 are preserved	dm_1 and dm_2 = stage 2
Hastière 19	Partial mandibular corpus extending from the left dm_2 to the right damaged dm_1	dm_2 = stage 3

Table 3. Preservation and wear at Sclaigneaux, a final/late Neolithic cave burial

Identifier	Preservation	Dental wear (Smith, 1984)
Sclaigneaux 115	Relatively complete lower maxilla and dental arcade holding dm^1 and dm^2 on both sides	dm^1 = stage 5; dm^2 = stage 4
Sclaigneaux 116	Relatively complete lower maxilla with dm^1 and dm^2 preserved on both sides	dm^1 and dm^2 = stage 3
Sclaigneaux 117	Left maxillary fragment with dm^1 and dm^2	dm^1 and dm^2 = stage 3
Sclaigneaux 118	Left maxillary fragment, preserving dm^2 and M^1	dm^2 = stage 5
Sclaigneaux 119	Left maxillary fragment and palate, preserving dm^1, dm^2 and M^1	dm^1 = stage 6; dm^2 = stage 4
Sclaigneaux 122	Left maxillary fragment with the deciduous molars preserved; dm^1 is slightly chipped	dm^1 = stage 7; dm^2 = stage 4
Sclaigneaux 124	Small right maxillary fragment holding dm^1, dm^2 and M^1	dm^1 = stage 5; dm^2 = stage 3
Sclaigneaux 125	Well-preserved right maxilla, with dm^1 and dm^2	dm^1 = stage 5; dm^2 = stage 4
Sclaigneaux 82	Small left corpus fragment holding dm_1 and dm_2	dm_1 = stage 5; dm_2 = stage 4

Table 4. Preservation and wear at Bois Madame, a final/late Neolithic cave burial

Identifier	Preservation	Dental wear (Smith, 1984)
BM mx 26	Left fragmentary maxilla, preserving dm^1 and dm^2	dm^1 and dm^2 = stage 4
BM mx 27	Left partial maxilla including most of the palate and alveolus, along with dm^1, dm^2 and M^1	dm^1 = stage 5; dm^2 = stage 4
BM Md 27	Right mandibular corpus fragment with a partial ramus including dm_1, dm_2 and M_1	dm_1 = stage 5; dm_2 = stage 4
BM Md 28	Right mandibular fragment with a complete ramus, and dm_1 and dm_2	dm_1 = stage 5; dm_2 = stage 4
BM Md 32	Left corpus and ascending ramus holding dm_2 and M_1	dm_2 = stage 4
BM Md 37	Right corpus fragment with dm_1 and dm_2	dm_1 = stage 4; dm_2 = stage 3

Table 5. Preservation and wear at Maurenne Caverne de la Cave, a cave burial with one middle and three final/late Neolithic dates

Identifier	Preservation	Dental wear (Smith, 1984)
Maurenne 22	Right maxillary fragment holding dm^1, dm^2 and the unerupted crown of M^1	dm^1 = stage 3; dm^2 = stage 2
Maurenne 23	Right maxillary fragment from the mesial margin of the M^1 crypt to di^1	dm^2 = stage 7; dm^2 = stage 4
Maurenne 24	Right maxillary fragment extending from the crypt of the M^1 crown to di^1 with only dm^1 (obscured by matrix) and dm^2	dm^2 = stage 2
Maurenne 25	Maxillary alveolus extending from a fully formed M^2 crown to the canine crypt, with dm^1, dm^2 and M^1	dm^1 = stage 6; dm^2 = stage 4
Maurenne 26	Maxillary alveolus, from the unerupted crown of M^1 to di^1, preserving dm^1 and dm^2	dm^1 = stage 4; dm^2 = stage 2
Maurenne 82	Nearly complete mandible holding dm_1 and dm_2 on both sides	dm_1 = stage 4; dm_2 = stage 3
Maurenne 85	Corpus fragment extending from the base of the left ascending ramus to right dm_1 crypt holding the left dm_1, dm_2 and M_1	dm_1 and dm_2 = stage 4

Methods

Dental impressions were created by the first author using a thin layer of polyvinylsiloxane (President Jet Plus Regular Body, Coltène-Whaledent) applied to the occlusal surface of *in situ* molars curated at the Royal Belgian Institute of Natural Sciences. Dental casts were created at Georgia State University using centrifuged epoxy resin and hardener (Beuhler), which was poured on the dental molds nestled within putty crucibles affixed beforehand with hardener (Beuhler). The casts dried for 24 hours before extraction.

Dental casts were scored by the second author using Hanihara (1961) and supplemented with scores for the hypoconulid (Cusp 5) on dm_2 and the metaconule (Cusp 5) on dm^2 from the ASUDAS (Turner et al., 1991; Scott and Irish, 2017), following Paul and Stojanowski (2015). The maxillary deciduous molars were scored for crown pattern of dm^1 and dm^2, Carabelli's trait on dm^2, and the presence of a metaconule (Cusp 5) on dm^2. For the mandibular deciduous molars, only dm_2 is considered following Hanihara (1961) and the traits scored included the protostylid, hypoconulid (Cusp 5), metaconulid (Cusp 7), the central ridge of the metaconid (CRM), and the distal trigonid crest (DTC). To validate the scores, photographs of the original material were consulted.

Results

Maxillary Traits

Crown pattern for dm^1 is noted in two individuals and varies considerably (Table 6). Specifically, at Sclaigneaux, one individual exhibits a large protocone and paracone, and is classified as a score of 2. In contrast, an individual from Maurenne Caverne de la Cave presents all four cusps but the hypocone and metacone are relatively modest in size corresponding to a score of 4- (Hanihara, 1961). The crown pattern for dm^2 is uniformly classified as a score of 4 (Hanihara, 1961). Carabelli's trait varies from a small pit in some individuals from Sclaigneaux to a large independent cusp on the dm^2 of Hastière Caverne M 39 (Figure 2). It is present at all sites except Bois Madame. A metacon-

Figure 2. The only metaconule observed is a small cuspule on the right dm^2 of Hastèire Caverne M 39 (a); this individual also exhibits a prominent Carabelli's cusp (b). Scale bar = 1 cm.

Table 6. Maxillary deciduous molar traits

Neolithic time period	Site	ID No.	Crown Pattern dm^1	Crown Pattern dm^2	Carabelli's trait dm^2	Metaconule (Cusp 5) dm^2
early/late	Hastière	38		4	5	0
	Hastière	38[1]		4		
	Hastière	39		4	7	1
final/late	Sclaigneaux	124	2	4	1	0
	Sclaigneaux	115		4	1	
	Sclaigneaux	122		4		
	Sclaigneaux	118		4		
	Sclaigneaux	117		4	6	0
	Sclaigneaux	116		4	3	0
	Sclaigneaux	119		4		
	Sclaigneaux	125		4	1	0
	Bois Madame	26		4		
	Bois Madame	27		4		
middle and final/late	Maurenne	24		4	2	0
	Maurenne	25		4		
	Maurenne	23		4		
	Maurenne	22	4-	4	5	0
	Maurenne	26		4	4	

ule is expressed only on Hastière Caverne M 39 (Figure 2) and is absent at Sclaigneaux and Maurenne Caverne de la Cave. In the Bois Madame sample, it could not be observed (see Table 6).

Mandibular Traits

A protostylid is present only on the dm_2 of a single individual from Hastière Caverne M (Figure 3). The metaconulid expression varies from a larger feature in Sclaigneaux (Hanihara score 3) and Maurenne Caverne de la Cave (Hanihara score 2) to its absence or low expression at Hastière Caverne M and Bois Madame (Table 7). A central ridge of the metaconid (CRM), or Cusp 7, is noted at all cave burials except Bois Madame, and a distal trigonid crest (DTC) is absent at Hastière Caverne M and Maurenne Caverne de la Cave, but present at Bois Madame (Figure 4). Where it could be examined, the hypoconulid (Cusp 5) was scored as either prominent (ASUDAS grade 5) such as at Hastière Caverne M and Sclaigneaux, or large (ASUDAS grade 4) as at Maurenne Caverne de la Cave, or both as is the case at Bois Madame (Figure 5).

Figure 3. The expression of a protostylid (white arrow) is visible on the left dm_2 of Hastière Caverne M 19. Scale bar = 1 cm.

Figure 4. A small metaconulid (a) and a large hypoconulid (b) can be observed on the right dm_2 of Maurenne 82. Scale bar = 1 cm.

Figure 5. The largest and most distinctive hypoconulid (cusp 5) is visible on the right dm_2 of Hastière Caverne M 18, identified by a white arrow. Scale bar = 1 cm.

Table 7. Mandibular deciduous molar traits

Neolithic time period	Site	ID No.	Protostylid dm_2	Metaconulid (Cusp 7) dm_2	CRM dm_2	DTC dm_2	Hypoconulid (Cusp 5) dm_2
early/late	Hastière	19	1	1		0	
	Hastière	18		0	2	0	5+
final/late	Sclaigneaux	82		3	2		5
	Bois Madame	37		0			5
	Bois Madame	32		1			
	Bois Madame	28					4
	Bois Madame	27				1	
middle and final/late	Maurenne	82		2	2	0	4
	Maurenne	85		0			

Frequencies of traits per Neolithic cave site

For dm^2, the crown pattern of Hastière Caverne M did not differ from the other collective burials. However, Hastière Caverne M was partially distinct from the other sites for Carabelli's trait, which was strongly expressed where it was demonstrably visible (Table 8). Furthermore, there is more variation in the expression of a metaconule on dm^2 at Hastière Caverne M, and this is the only site known to express a protostylid (Figure 3). Hastière Caverne M also differs in the expression of the metaconulid (Figure 4) when compared to the ones from the final/late collective burial of Sclaigneaux, and to a lesser extent Maurenne Caverne de la Cave (see Table 8). The final/late Neolithic cave burial of Bois Madame differs from Hastière Caverne M in exhibiting a distal trigonid crest (DTC), albeit of a low expression. Bois Madame is also distinct from the early/late Neolithic site of Hastière Caverne M for exhibiting greater variation in the expression of the hypoconulid (Cusp 5) on dm_2 (see Table 8).

Discussion

The morphology of the deciduous teeth has been examined in studies of modern humans (Hanihara, 1961; Edgar and Lease, 2007; Pilloud and Larsen, 2011), Pleistocene *Homo* (Smith and Tillier, 1989; Bailey and Hublin, 2006; Martinón-Torres et al., 2012; Hershkovitz et al., 2016; Zubova et al., 2016) and the African apes (Hardin and Legge, 2013). Because primary crown formation time is shorter, environmental pressures are reduced, resulting in a tendency of the deciduous dentition to preserve the ancestral condition more often than permanent successors (Paul and Stojanowski, 2017; Scott et al., 2018). Indeed, deciduous teeth have

Table 8. Pooled frequencies

			Grade								
Site	***N***	**Trait**	**0**	**1**	**2**	**3**	**4**	**4-**	**5**	**6**	**7**
Sclaigneaux[b]	1	Crown Pattern (dm^1)			1.00						
Maurenne[c]	1							1.00			
Hastière[a]	3	Crown Pattern (dm^2)					1.00				
Sclaigneaux[b]	8						1.00				
Bois Madame[b]	2						1.00				
Maurenne[c]	5						1.00				
Hastière[a]	2	Carabelli's (dm^2)							0.50		0.50
Sclaigneaux[b]	5			0.60		0.20				0.20	
Maurenne[c]	3				0.33		0.33		0.33		
Hastière[a]	2	Metaconule Cusp 5 (dm^2)	0.50	0.50							
Sclaigneaux[b]	4		1.00								
Maurenne[c]	2		1.00								
Hastière[a]	1	Protostylid (dm_2)		1.00							
Hastière[a]	2	Metaconulid Cusp 7 (dm_2)	0.50	0.50							
Sclaigneaux[b]	1					1.00					
Bois Madame[b]	2		0.50	0.50							
Maurenne[c]	2		0.50		0.50						
Hastière[a]	1	CRM (dm_2)			1.00						
Sclaigneaux[b]	1				1.00						
Maurenne[c]	1				1.00						
Hastière[a]	2	DTC (dm_2)	1.00								
Bois Madame[b]	1			1.00							
Maurenne[c]	1		1.00								
Hastière[a]	1	Hypoconulid Cusp 5 (dm_2)							1.00		
Sclaigneaux[b]	1								1.00		
Bois Madame[b]	2						0.50		0.50		
Maurenne[c]	1						1.00				

[a] early/late Neolithic; [b] final/late Neolithic; [c] middle and final/late Neolithic

been shown to exhibit greater efficacy in indicating relatedness than the permanent dentition (Kitagawa et al., 1995; Paul and Stojanowski, 2017), and are better at distinguishing groups than metric traits (Sciulli, 1977). Although deciduous and permanent teeth may not differ in proxies of environmental stability, such as fluctuating asymmetry (Guatelli-Steinberg et al., 2006), the primary dentition has fewer cases of agenesis or supernumerary teeth compared to adult successors (Scott et al., 2018).

The entire primary molar row (including the deciduous and permanent teeth) may reflect an underlying unified mechanism of expression. At the same time, the deciduous dentition appears to be governed by partially distinct genetic and developmental processes than the permanent teeth, such that the presence of a protostylid on dm_2 (see Figure 4) does not necessarily imply that this trait will appear on any of the permanent molars (Scott et al., 2018). Furthermore, Carabelli's trait tends to be more prevalent and more strongly expressed in dm^2 compared to M^1 (Kaul and Prakash, 1981; Bermúdez de Castro, 1989; Edgar and Lease, 2007; Scott et al., 2018). To the degree to which Carabelli's trait and the protostylid are informative about biological relationships, it would suggest that Hastière Caverne M does indeed differ from the other cave burials. In a study of early Neolithic Çatalhöyük, Pilloud (2009) found that for the deciduous dentition, Carabelli's trait of dm^2 and the presence of a protostylid on dm_2 significantly separated groups, and this appears to be true among the late Neolithic cave burials from Belgium.

Prehistoric deciduous teeth have been scarcely examined given a historical preference for the permanent dentition (Scott et al., 2018). An informative study by Scuilli (1977) described the deciduous dental morphology of prehistoric Amerindian hunter/gatherer/fishers and early Mississippian cultivators of the Ohio Valley. The crown form on dm^1 in the prehistoric Amerindian remains is most frequently four cusps (paracone, protocone, metacone and hypocone) like at Maurenne Caverne de la Cave (see Table 6). The crown form on dm^1 of an individual from Sclaigneaux including only the two mesial cusps was rarely found in 58 individuals from 12 sites (Sciulli, 1997). The dm^2 presents four cusps in both prehistoric Amerindian and Neolithic Belgian cave sites (Sciulli, 1977; see Table 8). However, Carabelli's trait is extremely rare among prehistoric Amerindians, whereas it is present and expressed strongly in three of the four Neolithic cave sites from Belgium, only being absent from Bois Madame (see Table 6). In comparison to Sciulli (1977) a metaconulid (Cusp 7) on dm_2 was found at lower frequencies compared to the results from this study, although the constraints of the small sample sizes must be taken into consideration (see Table 8). Each of the Neolithic cave burials exhibits a hypoconulid (Cusp 5) which compares to 97% of the prehistoric Amerindians who exhibit five or more cusps on dm2 (Sciulli, 1977).

Conclusions

The deciduous molars from the Neolithic caves of Belgium present considerable variation in the expression of traits. Crown pattern varies where it can be observed. Carabelli's trait is found at Hastière Caverne M, as well as the final/late Neolithic cave site of Sclaigneaux and at Maurenne Caverne de la Cave, although its expression varies. The individuals preserving dm_2 generally exhibit a large or very large hypoconulid (Cusp 5).

Given the wide range of radiometric dates from Maurenne Caverne de la Cave, it was expected to exhibit the greatest variability. Like Sclaigneaux, Maurenne Caverne de la Cave does present substantial variation in the expression of Carabelli's cusp and in the metaconulid (Cusp 7) compared to Hastière Caverne M. The resemblance of the two collective burials from Hastière rockshelter (Hastière Caverne M and Maurenne Caverne de la Cave) is not particularly strong although the number of individuals involved is severely constrained.

We expected to observe differences between the early/late collective burial of Hastière Caverne M and the final/late Neolithic sites of Sclaigneaux and Bois Madame. Hastière Caverne M does exhibit the most pronounced expression of Carabelli's cusp on dm^2, and this trait is found nearly universally in the sample (see Figure 2). Hastière Caverne M also has the largest hypoconulid (see Figure 5), and this cave burial is the only assemblage to express a protostylid on dm_2 (see Figure 3) and a metaconule on dm^2 (see Figure 2). Since no other site presents these distinctions, it appears that the deciduous dental morphology of the early/late Neolithic cave assemblage of Hastière Caverne M does indeed differ from the final/late Neolithic collective burials of Sclaigneaux and Bois Madame.

Population movement or displacement and/or secular changes may explain some of the differences in the frequencies of traits if the cave burials represent a single group of closely related peoples. Alternatively, these populations may have had only a limited amount of regional gene flow during the late Neolithic period. Previous studies indicate that deciduous dental morphology approximates, to a greater extent than the secondary dentition, the genetic relationships among individuals (Kitagawa et al., 1995; Paul and Stojanowski, 2017). To the degree to which this is also true of these Neolithic cave burials, it can be assumed the people represented at Hastière Caverne M were relatively isolated several centuries prior to a partial restructuring of the regional population associated with the Bronze Age.

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REFERENCES

Bailey S.E., Hublin J.-J. (2006). Dental remains from the Grotte du Renne at Arcy-sur-Cure (Yonne). *Journal of Human Evolution*, 50, 485–508.

Bermúdez de Castro J.M. (1989). The Carabelli trait in human prehistoric populations of the Canary Islands. *Human Biology*, 61, 117–131.

Bronk-Ramsey C., Higham T.F.G., Owen D.C., Pike W.G., Hedges R.E.M. (2002). Radiocarbon dates from the Oxford AMS system: datelist 31. *Archaeometry*, 44(3) Supplement 1:1–149.

Dumbruch I. (2003). Edute du site de l'abri-sous-roche du "Bois-Madame", Néolithique, à Arbre, dans la vallée du Burnot (Province de Namur). Etude anthropologique et archéologique, Volume I et II. MA thesis, Université Libre de Bruxelles.

Dumbruch I. (2007). Le Site de l'Abri-sous-Roche du "Bois-Madame" à Arbre (Province de Namur, Belgique). *Archæologia Mosellana*, 7, 609–612.

Edgar H.J.H., Lease L.R. (2007). Correlations between deciduous and permanent tooth morphology in a European American sample. *American Journal of Physical Anthropology*, 133, 726–734.

García-Martin C. (2000). Reconstitution du régime alimentaire par l'étude des micro-traces d'usure dentaire. MA thesis, Université Libre de Bruxelles.

Guatelli-Steinberg D., Sciulli P.W., Edgar H.J.H. (2006). Dental fluctuating asymmetry in the Gullah: tests of hypotheses regarding developmental stability in deciduous vs. permanent and male vs. female teeth. *American Journal of Physical Anthropology*, 129, 427–434.

Hanihara K. (1961). Criteria for classification of crown characters of the human deciduous dentition. *Journal of the Anthropological Society of Nipon*, 69, 27–45.

Hardin A.M., Legge S.S. (2013). Geographic variation in nonmetric dental traits of the deciduous molars of *Pan* and *Gorilla*. *International Journal of Primatology*, 34, 1000–1019.

Hershkovitz I., Smith P., Sarig R., Quam R., Rodriguez L., Garcia R., Arsuaga J.L., Barkai R., Gopher A. (2016). Middle Pleistocene dental remains from Qesem Cave (Israel). *American Journal of Physical Anthropology*, 144, 575–592.

Irish J.D. (2006). Who were the ancient Egyptians? Dental affinities among Neolithic through postdynastic peoples. *American Journal of Physical Anthropology*, 22, 529–543.

Kitagawa Y., Manabe Y., Oyamada J., Rokutanda A. (1995). Deciduous dental morphology of the prehistoric Jomon people of Japan – comparison of nonmetric characters. *American Journal of Physical Anthropology*, 97, 101–111.

Martinón-Torres M., de Castro J.M.B., Gomez-Robles A., Prado-Simon L., Arsuaga J.L. (2012). Morphological description and comparison of the dental remains from Atapuerca-Sima de los Huesos site (Spain). *Journal of Human Evolution*, 62, 7–58.Bottom of Form

Orban R., Polet C., Semal P., Leguebe A. (2000). La stature des Néolithiques mosans. *Bulletin de l'Institut Royal des Sciences Naturelles de Belgique, Série Sciences de la Terre,* 70, 207–222.

Paepe M. de (2007). Studie van de laat-neolithische menselijke resten uit een collectief graf te Sclaigneaux (provincie Namen, B.). MA thesis, Universiteit Gent.

Paul K.S., Stojanowski C.W. (2015). Performance analysis of deciduous morphology for detecting biological siblings. *American Journal of Physical Anthropology*, 164, 97–116.

Paul K.S., Stojanowski C.W. (2017). Comparative performance of deciduous and permanent dental morphology in detecting biological relatives. *American Journal of Physical Anthropology*, 157, 615–629.

Pilloud M.A. (2009). Community structure at Neolithic Çatalhöyük: biological distance analysis of household, neighborhood, and settlement. Ph.D. dissertation. The Ohio State University.

Pilloud M.A., Larsen C.S. (2011). "Official" and "practical" kin: inferring social and community structure from dental phenotype at Neolithic Catalhoyuk, Turkey. *American Journal of Physical Anthropology*, 145, 519–530.

Pilloud M.A., Edgar H.J.H., George R., Scott G.R. (2016). Dental morphology in biodistance analysis. In M. Pilloud & J. Hefner (Eds.), *Biological distance analysis: forensic and bioarchaeological perspectives* (pp. 109–133). San Diego: Elsevier.

Polet C. (2011). Les squelettes néolithiques découverts dans les grottes du basin mosan. In N. Cauwe, A. Hauzeur, I. Jadin, C. Polet & B. Vanmontfort (Eds.), *5200-2000 av. J.-C. premiers agriculteurs en Belgique* (pp. 85–94). Éditions du Cedarc.

Sciulli P.W. (1977). A descriptive and comparative study of the deciduous dentition of prehistoric Ohio Valley Amerindians. *American Journal of Physical Anthropology*, 47, 71–80.

Scott G.R., Turner C.G. (1997). *The anthropology of modern human teeth*. Cambridge: Cambridge University Press.

Scott G.R., Irish J.D. (2017). *Human tooth crown and root morphology*. Cambridge: Cambridge University Press.

Scott G.R., Turner C.G., Townsend G.C., Martinón-Torres M. (2018). *The anthropology of modern human teeth*, 2nd Edition. Cambridge: Cambridge University Press.

Semal P., García Martín C., Polet C., Richards M.P. (1999). Considération sur l'alimentation des Néolithiques du Bassin mosan: usures dentaires et analyses isotopiques du collagène osseux. *Notae Praehistoricae*, 19, 127–135.

Smith B.H. (1983). Dental attrition in hunter-gatherers and agriculturalists. Ph.D. dissertation, University of Michigan.

Smith B.H. (1984). Patterns of molar wear in hunter-gatherers and agriculturalists. *American Journal of Physical Anthropology*, 63, 39–56.

Smith P., Tillier A.-M. (1989). Additional infant remains from the Mousterian Strata, Kebara Cave (Israel). In O. Bar-Yosef & B. Vandermeersch (Eds.), *Investigation in South Levantine prehistory* (pp. 323–335). Oxford, England: British Archaeological Reports International Series 497.

Toussaint M. (2007). Les sépultures Néolithiques du basin mosan Wallon et leurs relations avec les bassins de la Seine et du Rhin. *Archaeologia Mosellana*, 7, 507–549.

Toussaint M., Orban R., Polet C., Semal P., Bocherens H., Masy P., García Martín C. (2001). Apports récents sur l'anthropologie des Mésolithiques et des Néolithiques mosans. *Anthropologica et Préhistorica*, 112, 91–105.

Turner C.G., II, Nichol C., Scott G.R. (1991). Scoring procedures for key morphological traits of the permanent dentition: The Arizona State University Dental Anthropology System. In M. A. Kelley & C. S. Larsen (Eds.), *Advances in dental anthropology* (pp. 13–31). New York: Wiley-Liss.

Vanderveken S. (1997). Etude anthropologique des sépultures néolithiques de Maurenne et Hastière (province de Namur). MA thesis, Université Libre de Bruxelles.

Zubova A.V., Stepanov A.D., Kuzmin Y.V. (2016). Comparative analysis of a Stone Age human tooth fragment from Khaiyrgas Cave on the Middle Lena (Yakutia, Russian Federation). *Anthropological Science*, 124, 135–143.

Data Set: Odontometric Comparisons of Permanent Dentition in Human Populations

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Mesiodistal and buccolingual tooth crown diameters constitute the most widely documented of anthropometric features. These two measurements provide significant information on the fields of human biological problems such as physical anthropology, oral biology, and orthodontics. In the past eighty years, odontometric data has brought a lot of benefit to anthropological and orthodontic research. Mizoguchi (1988) published a manuscript on the mesiodistal and buccolingual crown diameters of modern human populations worldwide, and Kieser (1990) wrote a book on human tooth size. However, after these publications, little else was done to document odontometric data from a global standpoint. The materials presented here summarize odontometric data from around the world. Additionally, data are presented on tooth agenesis.

I should be extremely happy to be of service to the researchers in dental anthropology as well as orthodontics.

REFERENCES

Kieser JA. 1990. Human Adult Odontometrics: The Study of Variation in Adult Tooth Size. Cambridge: Cambridge University Press.

Mizoguchi Y. (1988) A Statistical Analysis of Geographical Variation in Dental Size. A report of the Research Supported by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science and Culture, Japan. Pp. 1-124.

The full dataset is published as an Excel spreadsheet online as Supplemental Information, and contains summary data based on the following references. This manuscript can be cited in reference to this dataset.

Points to be paid attention are as follows

- Samples: population / group
- Locality: place / district / site / nationality
- Note: skull or cast/right side or left side/ comments etc.
- Period・Appendix：period / era / date / comments etc.
- Data Source: author
- M-D Crown Diameters: mesiodistal crown diameters
- B-L Crown Diameters: buccolingual crown diameters
- N: number of sample / number of teeth
- Mean: mean / average of both sides
- SD: standard deviation
- SE: standard error
- V: variance
- Modern Japanese: born from 1868 to 1945
- Recent Japanese: born from 1945 to present
- USA: United States of America
- UK: United Kingdom
- NZ: New Zealand

REFERENCES

Akiyama Y., Suzuki A, and Takahama Y. (1991) Tooth size of Japanese – General populations in Akita, Tanegashima, Tsushima, Okinawa and Taiwan－. *The Journal of Japan Orthodontic Society*, 50, 210-223. (In Japanese with English summary)

Alvesalo L. (1985) Dental growth in 47, XYY males and in conditions with other sex-chromosome anomalies. In, *The Y chromosome, Part B, Clinical Aspects of Y Chromosome Abnormalities*. Alan R. Liss, New York. Pp. 277-300.

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Aoyama T., Mastumoto K., Kobayasi T, and Mastuda T. (1957) The sexual variation of size in Japanese human teeth. *Journal of Osaka Dental University*, 20, 344-353. (In Japanese.)

Asakura M.(1975) Relationships of size and form of the remaining teeth to third molar agenesis. *The Aichi-Gakuin Journal of Dental Science,* 13, 270-302. (In Japanese with English summary.)

Axelsson G. and Kirveskari P. (1983) Crown size of permanent teeth in Icelanders. *Acta Odontologica* Scandinavica, 41, 181-186.

Bailit H.L., Dewitt、S.J., and Leigh R.A. (1968) The size and morphology of the Nasioi dentition. *American Journal of Physical Anthropology,* 28, 271-287.

Barnes D.S. (1969) Tooth morphology and other aspects of the Teso dentition. *American Journal of Physical Anthropology,* 30, 183-194.

Barrett M.J., Brown T. and MacDonald M.R. (1963) Dental observations on Australian Aborigines, MD crown diameters of permanent teeth. *Australian Dental Journal*, 8, 150-156.

Baume B.J. and Coohen M.M. (1971) Studies on agenesis in the permanent dentition. *American Journal of Physical Anthropology*, 35, 125-128

Ben-David Y., Hershkovitz I., Rubin D., Moscona D., and Ring B. (1992) Inbreeding effects on tooth size, eruption age and fluctuating asymmetry among South Sinai Bedouins. In P. Smith and E. Tchernov (Eds.), *Structure, function and evolution of teeth (*pp. 361-389). Tel Aviv: Freund Publishing House.

Bhasin M.K., Sharma A., Singh I.P., and Walter, H. (1985) Morphological and metric dental study on Indians. *Zeitschrift für Morphologie und Anthropologie,* 76,77-90.

Boyd R.C.(1972) Appendix IV: An odontometric and observational assessment of the dentition. In R.A. Little wood (Ed.), *Physical Anthropology of the Eastern Highlands of New Guinea*. University of Washington Press, Seattle and London.

Brace C.L. (1976) Tooth reduction in the Orient. *Asian Perspective*, 19, 203-219.

Brace C.L. (1979) Krapina, "Classic" Neanderthals, and the evolution of the European face. Journal *of Human Evolution*, 8, 527-550.

Brace C.L. and Nagai M. (1982) Japanese tooth size, past and present *American Journal of Physical Anthropology*, 59, 399-411.

Brace C.L. and Vitzthum V. (1984a) Human tooth size at Mesolithic, Neolithic and Modern levels at Niah Cave, Sarawak: Comparisons with other Asian Populations. *The Sarawak Museum Journal*, 33, 75-82.

Brace C.L., Shao X.-qing, and Zhang Z.-biao. (1984b) Prehistoric and modern tooth size in China. In F.H. Smith and F. Spencer (Eds), *The Origins of Modern Humans: A world Survey of the Fossil Evidence (*485-516). New York: Alan R. Liss.

Brook A.H., Griffin R.C., Smith R.N., Townsend G.C., Kaur G., Davis G.R., and Fearne J. (2009) Tooth size patterns in patients with hypodontia and supernumerary teeth. *Archives of Oral Biology*, 54 , 63 -70 (Supplement 1.)

Brown T. and Townsend G.C. (1979) Sex determination by single and multiple tooth measurements. *Occasional Papers in Human Biology*, 1, 1-16.

Brown T., Margetts B., and Townsend G.C. (1980) Comparison of MD crown diameters of the deciduous and permanent teeth in Australian Aborigines. *Australian Dental Journal*, 25, 28-33.

Brown P. (1987) Pleistocene homogeneity and Holocene size reduction: The Australian human skeletal evidence. *Archaeology in Oceania*, 22：41-67.

Cadien (1972) Dental Variation in Man. In, S.L. Washburn and P. Dohinow (Eds.), *Perspectives on human evolution* (199-222). New York: Holt, Rinehart, and Winston.

Calcagno J.M. (1986) Dental reduction in Post-Pleistocene Nubia. *American Journal of Physical Anthropology*, 70, 349-363.

Campbell T.D. (1925) *Dentition and palate of the Australian Aboriginal*. University of Adelaide, The Hassell Press, 4-26.

Chamla M.C. (1980) Ètude des variations métriques des couronnes dentaires des Nord-Africains, de L' Èpipaléolithique a l' époque actuelle. *L'Anthropologie* (Paris), 84,2 54-271.

Cho D. (1973) Studies on the tooth size of Koreans. *Journal of Growth*, 12, 1-18. （In Japanese with English summary.)

Christensen H.C. and Melsen B. (1974) Relationship between tooth size and third molar agenesis. *Scandinavia Journal of Dental Research,* 82, 552-556.

Christensen A.F. (1998) Odontometric microevolution in the Valley of Oaxaca, Mexico. *Journal of Human Evolution*, 34, 333-360.

Clinch L.M. (1960) A longitudinal study of the mesiodistal crown diameters of the deciduous teeth and their permanent successors. *European Journal of Orthodontics*, 29, 75–81.

Coppa A., Cucina A., Mancinelli D., Vargiu R., and Calcagno J.M. (1998) Dental anthropology of Central-Southern, Iron age Italy, The evidence of metric versus nonmetric traits. *American Journal of Physical Anthropology,* 107, 371-386.

Cruz L.C. (1971) A study of the mesiodistal crown diameters of permanent teeth among young Filipino adults. *The Journal of the Philippine Dental Association*、23, 14-18.

Dahlberg A.A. (1960) The dentition of the first agriculturists (Jarmo, Iraq). *American Journal of Physical Anthropology,* 18, 243-256.

Dennison J. (1979) Tooth size and sexual dimorphism in prehistoric New Zealand Polynesian teeth. *Archaeology and Physical Anthropology in Oceania*, 14, 123-128.

Doran G.A. and Freedman L. (1974) Metrical features of the dentition and arches of populations from Goroka and Lufa. Papua New Guinea. *Human Biology*, 46, 583-594.

Doris J.M., Bernard B.W., and Kuftinec M.M. (1981) A biometric study of tooth size and dental crowding. *American Journal of Orthodontics*, 79, 326-336.

Drennan M.R. (1929) The dentition of a Bushman tribe. *Annals of the South African Museum*, 24, 61-87.

Dutta P.C. (1983) An odontometric analysis of molar crown characters of Bronze Age Harappans. *Anthropologischer Anzeiger*, 41, 67-72.

Ebeling C.F., Ingervall B., Hedegard B., Hedegård B., and Lewin T. (1973) Secular changes in tooth size in Swedish men. *Acta Odontologishe Scandinavia,* 31, 141-147.

Forsberg C.M. (1992) Tooth size, spacing, and crowding in relation to erupting or impaction of third molars. *American Journal of Orthodontics and Dentofacial Orthopedics*, 2, 57-62.

Frayer D.W. (1977) Metric dental change in the European Upper Paleolithic and Mesolithic. *American Journal of Physical Anthropology*, 46, 109-120.

Freedman L. and Lofgren M. (1981) Odontometrics of Western Australian Aborigines. *Archaeology in Oceania*, 16, 87-93.

Gabriel A. (1955) The correlation of the size of human teeth with one another and with certain jaw measurements. *The Dental Journal of Australia*, 27, 174-186.

Garn S.M., Lewis A.B., and Kerewsky R.S. (1964) Sex difference in tooth size. *Journal of Dental Research*. 43, 306

Garn S.M., Lewis A.B., Swindler D.R., and Kerewsky R.S. (1967) Genetic control of sexual dimorphism in tooth size. *Journal of Dental Research*, 46, 963-972. (Supplement to No.5).

Garn S.M., Lewis A.B., and Walenga A.L. (1968) Maximum-confidence values for the human mesiodistal crown dimension of human teeth. *Archives Oral Biology,* 13, 841-844.

Garn S.M., Osborne R.H., and McCabe K.D. (1979) The effect of prenatal factors on crown dimensions. *American Journal of Physical Anthropology*, 51, 665-678.

Ghose L.J. and Bahdady V.S. (1979) Analysis of the Iraqi dentition, mesiodistal diameters of permanent teeth. *Journal of Dental Research*, 58, 1047-1054.

Gonda K. (1959) On the sexual differences in the dimensions of the human teeth. *Journal of the Anthropological Society of Nippon*, 67, 151-163. (In Japanese with English summary.)

Goose D.H. (1963) Dental measurement: An assessment of its value in anthropological studies. In, D.R. Brothwell (Ed.), *Dental Anthropology* (pp. 125 -148). New York: Pergamon.

Goose D.H. (1967) Preliminary study of tooth size in Families. *Journal of Dental Research*, 5, 959-962. (Supplement).

Green D.L. and Ewing G.H. (1955) Dentition of a Mesolithic Population from Wadi Halfa, Sudan. *American Journal of Physical Anthropology*, 27, 41-56.

Gungor A.Y. and Turkkahraman H. (2013) Tooth sizes in nonsyndromic hypodontia patients. *The Angle Orthodontist*, 83, 16-21.

Hamada R., Kondo S., and Wakatsuki E. (1997) Odontometrical analysis of Filipino dentition. *The Journal of Showa University Dental Society*, 17,197-207.

Hanihara K. (1976) Statistical and comparative studies of the Australian aboriginal dentition. *The University Museum The University of Tokyo Bulletin*, No.11, 1-57.

Hanihara K. (1977) Distances between Australian Aborigines and certain other populations based on dental measurements. *Journal of Human Evolution*, 6,403-418.

Hanihara K. (1979) Dental traits in Ainu, Australian Aborigines, and New World populations. In W.S. Laughline and A.B. Harper (Eds.), *The first Americans, Origins, Affinities, and Adaptations* (pp 125-134). New York: Stuttgart.

Hanihara K. and Koizumi K. (1979) Sexing from crown diameters in the permanent teeth by discriminant function method. *Journal of the Anthropological Society of Nippon*, 87, 445-456. (In Japanese with English summary.)

Hanihara K. and Ueda H. (1979) Crown diameters in Japanese-American F1 hybrids. *Ossa*, 6, 105-114.

Hanihara T. (1989) Comparative studies of geographically isolated populations in Japan based on dental measurements. *Journal of the Anthropological Society of Nippon*, 97, 95-107.

Hanihara, T. (1990a) Affinities of the Philippine Negritos with Japanese and the Pacific populations based on dental measurements, The basic population in East Asia, I. *Journal of the Anthropological Society of Nippon*, 98, 13-27.

Hanihara T. (1990b) Studies on the affinities of Sakhalin Ainu based on dental characters, The basic populations in East Asia, III. *Journal of the Anthropological Society of Nippon*, 98, 425-437.

Harris E.F. and Nweeia M.T. (1980) Tooth size of Ticuna Indians, Colombia, with phenetic comparisons to other Amerindians. *American Journal of Physical Anthropology*, 53, 81-91.

Harris E.F. and Bailit H.L. (1987) Odontometric comparisons among Solomon Islanders and other Oceanic peoples. In J.S. Friedlander and W.W Howells (Eds.), *The Solomon Islands Project: A Long -Term Study of Health, Human Biology, and Culture Change* (pp. 215-264). Cambridge: Oxford University Press.

Harris E.F. and Rathbun T.A. (1989) Small tooth sizes in a nineteenth century South Carolina plantation slave series. *American Journal of Physical Anthropology*, 78, 411-420.

Harris E.F., Potter R.H., and Lin J. (2001) Secular trend in tooth size in urban Chinese assessed from two-generation family data. *American Journal of Physical Anthropology*, 115, 312-318.

Haeussler A.M., Irish J.D., Morris D.H., and Turner C.G. II (1989) Morphological and metrical comparison of San and Central Sotho dentitions from Southern Africa. American *Journal of Physical Anthropology,* 78, 115-122.

Hinton R.J., Smith M.O., and Smith F.H. (1980) Tooth size changes in Prehistoric Tennessee Indians. *Human Biology*, 52, 229-245.

Hosaka T. (1950) Study of the Chinese dentition. (Quoted by Sunaga, 1950). (In Japanese.)

Houghton P. (1978) Polynesian mandibles. *Journal of Anatomy*, 127, 251-260.

Inoue N., Takagi O., Kamegai T., and Ito G. (1983a) Studies on Tooth to Denture Base Discrepancy Consequent upon Human Evolution. II. Researches in Modern Japanese. 1. Investigation at Koromogawa Village, Iwate. *Report of the study supported by a Grant-in-Aid for Co-operative Research of the Ministry of Education, Science and Culture*, Japan.

Inoue N., Ito G., Inoue M., and Kamegai T. (1983b) Studies on Tooth to Denture Base Discrepancy Consequent upon Human Evolution. II. Researches in Modern Japanese. 2. Investigation at Kagoshima city, Kagoshima. *Report of the study supported by a Grant-in-Aid for Co-operative Research of the Ministry of Education, Science and Culture, Japan*.

Inoue N., Kamegai T., and Ito G. (1983c) Studies on Tooth to Denture Base Discrepancy Consequent upon Human Evolution. Researches in Modern Japanese. 3. Investigation at Yahaba town, Iwate. *Report of the study supported by a Grant-in-Aid for Co-operative Research of the Ministry of Education, Science and Culture, Japan*.

Inoue N., Ito G., Inoue M., and Kamegai T. (1983d) Studies on Tooth to Denture Base Discrepancy Consequent upon Human Evolution.II. Researches in Modern Japanese. 4. Investigation at Bohnotsu-Cho, Kagoshima. *Report of the study supported by a Grant-in-Aid for Co-operative Research of the Ministry of Education, Science and Culture, Japan.*

Inoue N., Ito G., Inoue M., and Kamegai T. (1983e) Studies on Tooth to Denture Base Discrepancy Consequent upon Human Evolution. II. Researches in Modern Japanese. 5. Investigation at Tokunoshima, Kagoshima. *Report of the study supported by a Grant-in-Aid for Co-operative Research of the Ministry of Education, Science and Culture, Japan*.

Inoue N., Kuwahara M., Ito G., and Inoue M., (1983f) Studies on Tooth to Denture Base Discrepancy Consequent upon Human Evolution. II. Researches in Modern Japanese. 6. Investigation at Nagoya city, Aichi. *Report of the study supported by a Grant-in-Aid for Co-operative Research of the Ministry of Education, Science and Culture, Japan*.

Inoue N., Takahashi Y., Sakashita R., Wu M-L., Nozaki T., Chen C-W., Kamegai T., and Shiono K. (1992) Morphometrically and dental pathological studies on skulls from Yin-Shang Period. *Journal of the Anthropological Society of Nippon*, 100, 1-29.

İşcan M.Y. (1989) Odontometric profile of a prehistoric Southeastern Florida population. *American Journal of Physical Anthropology*, 78, 3-8.

Iwagaki H. (1937) Statistical studies on the variation of teeth and arches. *Monthly Dental* Report, 17, 519-552. (In Japanese with English summary.)

Jacob T. (1967) Racial identification of the Bronze age human dentitions from Bali, Indonesia. Journal *of Dental Research,* 46, 903-910.

Jacobson A. (1982) The *dentition of the South African negro.* Birmingham: U.A.B. School of Dentistry Publishers.

Janzer O. (1921) Die Zahne der Neu-Pommen. *Vierteljhrsschr Zahnhlk*, 43, 289-319 (in German)

Kaburagi M., Ishida H., Goto M., and Hanihara T. (2010) Comparative studies of the Ainu, their ancestors, and neighbors, assessment based on metric and nonmetric dental data. *Anthropological Science*, 118, 95-106.

Kamijyo Y. (1962) *Anatomy of permanent dentition*. Tokyo: Anatom Co. (In Japanese.)

Kanazawa E., Matsuno M., Nakabayashi T., Igarashi Y., and Nagai A. (1998) Tooth size of living peoples in Western and Eastern Micronesian populations. *Anthropological Science*, 106, 199-208.

Kanazawa E., Matsuno M., Sekiguchi H., Suzuki T., Satake T., Sasaki K., and Igarashi Y. (2000) Tooth size of people in Wabag, Papua New Guinea Highlanders and its comparison with Pacific peoples. *Anthropological Science*, 108, 169-181.

Kean M. R. and Houghton P. (1990) Polynesian face and dentition, Functional perspective. *American Journal of Physical Anthropology*, 82, 361-370.

Khalaf K., Robinson D.L., Elock C., Smith R.N., and Brook A.H. (2005) Tooth size in patients with supernumerary teeth and a control group measured by image analysis system. *Archives of Oral Biology*, 50, 243-248.

Kibi N. (1989) Physical affinity of the Pre- and Protohistoric Japanese of Kinki and Chugoku districts as viewed from dental measurements. *Anthropological Reports*, 48,1-25. (In Japanese.)

Kieser J.A. (1985a) An odontometric analysis of the early Griqua dentition. *Anthropologischer Anzeiger*, 43, 51-58.

Kieser J.A., Groeneveld H.T., and Preston C.B. (1985b) A metric analysis of the South African Caucasoid dentition. *Journal of Dental Association (Assn) South Africa*, 40, 121-125.

Kieser J.A., Groeneveld H.T., and Preston C.B. (1985c) An odontometric analysis of the Lengua Indians dentition. *Human Biology*, 57, 611-620.

Kieser J.A., Cameron N., and Groeneveld H.T. (1987) Evidence for a secular trend in the Negro dentition. *Annals of Human Biology*, 14, 517-532.

Kieser J.A. (1990) *Human Adult Odontometrics*. Cambridge: Cambridge University Press.

Kirch (1989) Human skeletal and dental remains from Lapita sites (1600-500BC) in the Mussau Islands, Melanesia. *American Journal of Physical Anthropology*, 79, 63-76.

Kirveskari P., Hansson H., Hedegard B., and Karlsson U. (1978) Crown size and hypodontia in the permanent dentition of Modern Skolt Lapps. *American Journal of Physical Anthropology*, 48, 107-112.

Kogiso T. (1982) A morphological study of sexual dimorphism in human masticatory apparatus. *The Aichi-Gakuin Journal of Dental Science*, 20, 229-267. (In Japanese with English summary.)

Koyoumdjisky-Kaye E., Zilberman Y., and Zeevi Z. (1976) A comparative study of tooth and dental arch dimensions in Jewish children of different ethnic descent. 1. Kurds and Yemenites. *American Journal of Physical Anthropology*, 44,437-444.

Koyoumdjisky-Kaye E., Zilberman Y., and Hazen O. (1977) A comparative study of tooth and dental arch dimensions in Circassian and Druse children. *Zeitschrift für Morphologie und Anthropologie*, 68, 298-306.

Koyoumdjisky-Kaye E., Steigam S., and Gudelevitch B. (1978) A comparative study of tooth and dental arch dimensions in Israel children of Cochin and North-African descent. *Zeitschrift für Morphologie und Anthropologie*, 69, 32-42.

Kudo K. (1985) A physical anthropological study of the teeth in the Bunun tribe of Taiwan aborigines. *The Journal of the Kyushu Dental Society*, 39,201-229. (In Japanese with English summary.)

Lavelle C.L.B., Ashton E.H., and Flinn R.M. (1970) Cusp pattern, tooth size and third molar agenesis in the human mandibular dentition. *Archives Oral Biology*, 15, 227-237.

Lavelle L.C.B. (1972) Maxillary and mandibular tooth size in different racial groups and in different occlusal categories. *American Journal of Orthodontics*, 61, 29-37.

Le Bot P. and Salmon D. (1977) Congenital defects of the upper lateral incisors (ULI), Condition and measurements of the other teeth, measurements of the superior arch, head and face. *American Journal of Physical Anthropology*, 46, 231-244.

Lee G.T.R. and Goose D.H. (1972) The dentition of Chinese living in Liverpool. *Human Biology*, 44,563-572.

Liao J.Y. (1984) Tooth size of Chinese in Taiwan. *Aichi-Gakuin Journal of Dental Science*, 22, 111-140. (In Japanese with English summary.)

Liu K.L. (1977) Dental condition of two tribes of Taiwan Aborigines — Ami and Atayal. *Journal of Dental Research,* 56, 117-127.

Lukcas J.R. (1985) Tooth size variation in prehistoric India. *American Anthropologist*, 87, 811-825.

Macho G.A. and Moggi-Cecchi (1992) Reduction of maxillary molars in Homo sapiens sapiens, A different perspective. *American Journal of Physical Anthropology*, 87, 151-159.

Manabe Y., Kitagawa Y., Koyamada J., and Rokutanda A. (1996) Sexing from crown diameters in the permanent dentition by discriminant function analysis—An assessment in the Yami tribe, Taiwan aborigine—. *Japanese Association for Oral Biology*, 38, 7-13. (In Japanese with English summary.)

Matsumura H. (1989a) Geographical variation of dental measurements in the Jomon population. *Journal of the Anthropological Society of Nippon*, 97, 493-512.

Matsumura H. (1990) Geographical variation of dental characteristics in the Japanese of the Protohistoric Kofun period. *Journal of the Anthropological Society of Nippon*, 98, 439-449.

Matsumura H. (1994) A microevolutional history of the Japanese people from a dental characteristics perspective. *Anthropological Science*, 102, 93-118.

Matsumura H. (1995a) Dental Characteristics of the Neolithic Remains from Jiangnan. In, *Studies on the Human Skeletal Remains from Jiangnan*, China. (Eds.) Yamaguchi B. and Xianghong H.), *National Science Museum Monographs* No. 10, 87-95.

Matsumura H. (1995b) Dental characteristics affinities of the Prehistoric to modern Japanese with the East Asians, American Natives and Australo-Melanesians. *Anthropological Science*, 103, 235-261.

Matsumura H. (1998) Native or Migrant Lineage? – The Aeneolithic Yayoi people in Western and Eastern Japan –, *Anthropological Science*, 106, 17-25. (Supplement).

Matsumura H., Cuong N.L., Thuy N.K., and Anezaki T. (2001) Dental morphology of the early Hoabinian, the Neolithic Da But and the Metal age

Dong Son civilized peoples in Vietnam. *Zeitschrift für Morphologie und Anthropologie*, 83, 59-73.
Matsumura H. (2002) The possible origin of the Yayoi migrants based on the analysis of the dental characteristics. In T. Nakahashi and M. Li (Eds.), *Kyusyu Ancient People in the Jiangnan Region* (pp 61 *-72)*. China: University Press, Fukuoka.
Matsumura H. and Hudson M.J. (2005) Dental perspectives on the population history of Southeast Asia. *American Journal of Physical Anthropology*, 127, 182-209.
Matsumura H., Oxenham M.F., Dodo Y., Domett K., Thuy N.K., Cuong N.L., Dung N.K., Huffer D., and Yamagata M. (2008) Morphometric affinity of the late Neolithic human remains from Man Bac, Ninh Binh Province, Vietnam, key skeletons with which to debate the 'two layer' hypothesis. *Anthropological Science,* 116, 135-148.
Matsumura H. and Dodo Y. (2009) Dental characteristics of Tohoku residents in Japan, implications for biological affinity with ancient Emishi. *Anthropological Science*, 117, 95-105.
Matsumura H., Ishida H., Amano T., Ono H., and Yoneda M. (2009) Biological affinities of Okhotsk-culture people with East Siberians and arctic people based on dental characteristics. *Anthropological Science*, 117, 121-132.
Matsumura H., Domett K.M., and O'reilly D.J.W. (2011) On the origin of pre-Angkorian peoples, perspectives from cranial and dental affinity of the human remains from Iron Agae Phum Snay, Cambodia. *Anthropological Science*, 119, 67-79.
Matsuno M. (1997) Dental anthropological study on tooth size in Fiji, Western Samoa and Kiribati. *Nihon University Journal of Oral Science*, 23, 33-52. (In Japanese with English summary.)
Mayhall J.T. (1979) The dental morphology of the Inuit of the Canadian Central Arctic. *Ossa*, 6, 199-218.
McKeown H.F., Robinson D.L., Elcock C., Al-Sharood M., and Brook A.H. (2002) Tooth dimensions in hypodontia patients, their unaffected relatives and a control group measured by a new image analysis system. *European Journal of Orthodontics,* 24, 131-141.
Mènard J. (1975) L'evolution des dents des Français. Bulletin Et Mèm. *Society D'Anthropology, Paris*, 2 , 45-59. (serie XIII).
Mijsberg W.A. (1931) On sexual differences in the teeth of Javanese. *Koninklijke Akademie voor Wetenschap*, 34, 1111-1115.
Miura F., Ichijyo T., Soma K., Kuroki T., Fukawa T., Maeda M., Tomita K., Hanada K., Ito A., Katagiri M., Jano A., Salas M.E., Pompa J.A., and Andrino J.A. (1989) Dental anthropological study of the Central American Indians. *Journal of the Japanese Stomatological Society*, 56, 409-428. (In Japanese with English summary.)
Miura F., Soma K., Kuroki T., Fukawa T., Ishida T., Ichijo T., Hanada K., Terada K., Fu M., Liu K., and Haung S. (1991) Dental anthropological study of Mongoloid in China. Journal *of the Japanese Stomatological Society*, 58, 566-579. (In Japanese with English summary.)
Miyabara T. (1915) An anthropological study of the masticatory system in the Japanese, (I) The teeth. *The Dental Cosmos*, 57, 739-749. (In Japanese with English summary.)
Mizoguchi Y. (1981) Variation units in the human permanent dentition. *Bulletin of the National Science Museum, Tokyo Series D* (Anthropology), 7, 29-39.
Mizoguchi Y. (1985) Shovelling, A Statistical Analysis of Its Morphology. *The University Museum. University of Tokyo Press, Tokyo*. Bulletin No. 26, 1-176.
Mizoguchi Y. (1986) Correlated asymmetries detected in the tooth crown diameters of human permanent teeth. *Bulletin of the National Science Museum, Tokyo Series D* (Anthropology), 12, 25-45.
Mizoguchi Y. (1988) A Statistical Analysis of Geographical Variation in Dental Size. *A report of the Research Supported by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science and Culture, Japan*. Pp. 1-124.
Moorrees C.F.A. (1957) *The Aleut Dentition.* Cambridge: Harvard University Press.
Moorrees C.F.A., Thomsen S.O., Jensen E., and Yen P.K.J. (1957) Mesiodistal crown diameters of deciduous and permanent teeth. *Journal of Dental Research,* 36, 39-47.
Moorrees C.F.A. (1959) *The Dentition of the Growing Child*. Cambridge, Harvard University Press.
Nagamine Y. (1933) On the correlations between portions of dental morphology. *Journal of the Nippon Dental Association*, 26, 37-52. (In Japanese.)
Nagaoka K. and Kuwahara Y. (1993) Normal standards for various Roentgen cephalometric and cast model analysis in present day Japanese adults, Part I. *The Journal of Japan Orthodontic Society*, 52, 467-480. (In Japanese with English summary.)
Nagaoka T. and Hirata K. (2003) Geographical variation in Japanese tooth size in the Edo period. *Anthropological Science (J-Series),* 111, 143-154. (In Japanese with English summary.)
Nagaoka T. and Hirata K. (2006) Tooth size of the medieval period people of Japan. *Anthropological Science*, 114, 117-126.
Nagayama T. (1984) A physical anthropological study of the teeth in the tribe of Taiwan aborigines, Rukai. *The Journal of the Kyushu Dental Society*, 38, 971-1002. (In Japanese.)
Nakano M., Suzuki A., Murakami T., and Takahama Y. (1993) Tooth sizes and dentofacial forms of the orthodontic patients with tooth crowding. *The Journal of Japan Orthodontic Society*, 52, 104-118. (In Japanese with English summary.)

Nelson C.T. (1938) The teeth of the Indians of Pecos Pueblo. *American Journal of Physical Anthropology*, 23, 261-293.

Okazaki K. (2005) Sex assessment of subadult skeletons based on tooth crown measurements: An examination on the interpopulational variation of sex differences and an application to excavated skeletons. *Anthropological Science*（J-Series), 113,139-159. (In Japanese with English summary.)

Ono A. (1957) Anthropological studies on the teeth of the Yayoi-age men from Mitsu, Kanazaki-gun, Saga-prefecture. *Journal of the Anthropological Society of Nippon*, 4, 423-462. (In Japanese.)

O'Rourke D.H., and Crawford M.H. (1980) Odontometric microdifferentiation of transplanted Maxican Indian populations, Cuanalan and Saltillo. *American Journal of Physical Anthropology*, 52, 421-434.

Otsubo J. (1957) A study on the tooth material in Japanese adults of normal occlusion, its relationship to coronal and basal arches. *The Journal of Japan Orthodontic Society*, 16, 36-46. (In Japanese.)

Oyamada J. (1992) Tooth crown size of Yayoi people in the North-West and the North of Kyushu. *Journal of the Anthropological Society of Nippon*, 100, 83-100. (In Japanese with English summary.)

Oyamada J., Manabe Y., Kitagawa Y., Rokutanda A., and Nagashima S. (1995) Tooth size of the Protohistoric Kofun people in Southern Kyushu, Japan. *Anthropological Science*, 103, 49-60.

Ozaki T., Satake T., and Kanazawa E.（1987) Morphological significance of root length variability in comparison with other crown dimensions. I. Basic statistics and sex difference. *Journal of Nihon University School of Dentistry*, 29, 233-240.

Pedersen O.P. (1949) *The East Greenland Eskimo Dentition*. Copenhagen: CA Reitzel.

Perzigian A.J. (1975) Natural selection on the dentition of an Arikara population, *American Journal of Physical Anthropology*, 42, 63-69.

Perzigian A.J. (1976) The dentition of the Indian Knoll skeletal population odontometrics and cusp number. *American Journal of Physical Anthropology*, 44, 113-122.

Phenice T.W. (1969) *An analysis of the human skeletal material from burial mounds in north central Kansas*. University of Kansas Publications in Anthropology, Lawrence.

Potter R.H.Y., Alcazaren A.B., Herbosa F.M., and Tomaneng J. (1981) Dimensional characteristics of the Filipino dentition. *American Journal of Physical Anthropology*, 55, 33-42.

Prakash S., Kaul V., and Kanta S. (1979) Observations on the Bhutanese dentition. *Human Biology*, 51, 23-30.

Radnzic D.（1987) Comparative study of mesiodistal crown diameters and arch dimensions between indigenous British and Pakistan immigrant populations. *American Journal of Physical Anthropology*, 72, 479-483.

Richardson E.R. and Malhotra S.K. (1975) Mesiodistal crown dimensions of the permanent dentition of American Negroes. *American Journal of Orthodontics,* 68, 157-64.

Rosenzweig K.A. and Zilberman Y. (1967) Dental Morphology of Jews from Yemen and Cochin. *American Journal of Physical Anthropology*, 26, 15-22.

Rozenzweig K.A. and Zilberman Y. (1969) Dentition of Bedouin in Israel. II. Morphology. *American Journal of Physical Anthropology*, 31, 199-204.

Sakai T., Hanamura H., and Ohno N. (1971) Tooth size of the Pashtun and Tajik in Afghanistan. *Journal of the Anthropological Society of Nippon*, 79, 159-177. (In Japanese with English summary.)

Sanui Z. (1960) Dental anthropological studies of the Yayoi people in Doigahama remains, Yamaguchi District. *Anthropological Association,* 7, 861-884. (In Japanese with English summary.)

Sasaki M. (1982) A physical anthropological study of the teeth in the tribe of Taiwan aborigines, Paiwan. *The Journal of the Kyushu Dental Society*, 36, 433-467. (In Japanese with English summary.)

Sciulli P.W. (1979) Size and morphology of the permanent dentition in prehistoric Ohio Valley Amerindians. *American Journal of Physical Anthropology*, 50, 615-628.

Scott E.C. (1979) Increase in tooth size in prehistoric coastal Peru, 10000-1000 BC. *American Journal of Physical Anthropology,* 50, 251-258.

Seipel C.M., (1946) Variation in tooth position, a metric study of variation and adaptation in the deciduous and permanent dentitions. *Swedish Dental Journal,* 39, 1-176. (Supplement)

Selmer-Olsen R. (1949) An odontological study of the Norwegian Lapps. *Skrift Norske Vidensk-Akademi,* 3, 1-167.

Sharma J.C. (1983) Dental morphology and odontometry of the Tibetan immigrants. *American Journal of Physical Anthropology*, 61, 495-505.

Sharma J.C. (1985) Evolutional significance of dental morphology and odontometry. In V.R. Reddy (Ed.), *Dental Anthropology, Application and Methods* (pp 251-267). New Dehli: Inter-India Publications.

Smith P. (1972) Regional variation in tooth size and pathology in fossil hominids. American *Journal of Physical Anthropology,* 47, 459-466.

Smith P. (1977) Selective pressures and dental evolution in Hominids. *American Journal of Physical Anthropology*, 47, 358-458.

Smith P. (1979) Regional diversity in epipaleolithic populations. *OSSA*, 6, 243-250.

Smith P., Brown T., and Wood W.B. (1981) Tooth size and morphology in a recent Australian Aboriginal population from Broadbeach, South East Queensland. *American Journal of Physical Anthropology*, 55, 423-432.

Smith P. (1982) Dental reduction, selection or drift? In B. Kurtén (Ed.), *Teeth: Form, Function and Evolution* (pp. 366-381). New York: Columbia University Press.

Smith P. and Shegev M. (1988) The dentition of Nubians from Wadi Halfa, Sudan, an evolutionary perspective. *Journal of the Dental Association of South Africa*, 43, 539-541.

Snow C.E. (1974) *Early Hawaiians: An Initial Study of Skeletal Remains from Mokapu, Oahu*. Lexington: The University Press of Kentucky.

Sofaer J.A., Bailit H.L., and MacLean C.J. (1971) A developmental basis for differential tooth reduction during hominid evolution. *Evolution*, 25, 509-517.

Sunaga T. (1952) Morphology and anatomical studies in the dentition of Southern Chinese Fujian. *The proceedings of Numata research institute,* 4, 1-60. (In Japanese.)

Suzuki A. and Takahama Y. (1992) Tooth crown affinities among five populations from Akita, Tsushima, Tanegashima, Okinawa in Japan, and Middle Taiwan. *Journal of the Anthropological Society of Nippon*, 100, 171-182.

Suzuki A., Han B-J., Takahama Y., Son W-S., Itou K., and Matsuura S. (1994) Tooth crown affinities among South Koreans, Central Taiwanese, and Certain Japanese populations. *Anthropological Science,* 102, 271-283.

Suzuki M. and Sakai T. (1957) The living Sakhalin Ainu dentition. *Anthropological Reports, Niigata University,* 18, 303-346. (In Japanese with English summary.)

Suzuki N. (1993) Generational differences in size and morphology of tooth crowns in the young modern Japanese. *Anthropological Science*, 101, 405-429.

Suzuki T. (2007) Establishment of Edo people living in central Tohoku area based on tooth size. *Tohoku University Dental Journal,* 26, 81-100. (In Japanese.)

Swindler D.R., Drusini A.G., Cristino C., and Ranzano C. (1998) Comparison of molar crown size of precontact Easter Islanders with other Pacific groups. In, J.T. Mayhall and T. Heikkinen (Eds.), *Dental Morphology* (pp 63-73). Oulu University Press.

Swindler D.R. and Weisler M.I. (2000) Dental size and morphology of Precontact Marshall Islanders (Micronesia) compared with other Pacific islanders. *Anthropological Science*, 108, 261-282.

Takehisa S. (1957) An anthropological and morphological comparative study of American White teeth and Japanese teeth. *Shikagakuhou* 57, 1-41. (In Japanese.)

Takei T. (1990) An anthropological study on the tooth crown morphology in the Atayal tribe of Taiwan Aborigines, Comparative analysis between Atayal and some Asian-Pacific populations. *Journal of the Anthropological Society of Nippon*, 98, 337-351. (In Japanese with English summary.)

Taverne P.P. (1980) *Een Fysisch-Anthropologisch Onderzoek van de Gebitten van Vier Surinaamse Bevolkingsgroepen*. Thesis, Rijksuiversiteit te Groningen. (In Dutch with English summary.)

Thilander B. (2009) Dentoalveolar development in subjects with normal occlusion. A longitudinal study between the ages of 5 and 31 years. *European Journal of Orthodontics,* 31, 109-120.

Thompson A.R. (2013) Odontometric determination of sex at Mound 72, Cahokia. *American Journal of Physical Anthropology*, 151, 408-419.

Thomsen S. (1955) Dental morphology and occlusion in the people of Tristan da Cunha. *Results of the Norwegian Scientific Expedition to Tristan da Cunha,* 1937-1938. No.25, 1-61.

Todaka Y., Oyamada J., Manabe Y., Kitagawa Y., Kato K., and Rokutanda A.(2003) The relationship between immigration and the prevalence of dental caries in the Yayoi people. *Anthropological Science,* 111, 265-292.

Tokitsu K. (1960) Anthropological studies on the palatum, the mandible and the teeth of the Atayal (Musha), Taichu prefecture, Formosa. *Quarterly Journal of Anthropology*, 7, 37-132. (Supplement), (In Japanese with English title.)

Toma T., Hanihara T., Sunakawa H., Haneji K., and Ishida H. (2007) Metric dental diversity of Ryukyu Islanders: a comparative study among Ryukyu and other Asian populations. *Anthropological Science*, 115, 119-131.

Townsend D.C. and Brown T. (1979) Tooth size characteristics of Australian Aborigines. *Occasional Papers in Human Biology*, 1, 17-38.

Townsend D.C. (1983) Tooth size in children and young adults with trisomy 21 (Down) syndrome. *Archives of Oral Biology*, 28, 159-166.

Townsend D.C. and Alvesalo L. (1985) Tooth size in 47, XYY males, evidence for a direct effect of the Y chromosome on growth. *Australian Dental Journal*, 30, 268-272.

Turner C..G. and Swindler D.R. (1978) The dentition of the New Britain West Nakanai Melanesians. VIII. People of the Pacific. *American Journal of Physical Anthropology*, 49, 361-372.

Tsuru H. (1978) An anthropological study on the physical traits of teeth in the inhabitants of Tanegashima Island. *The Journal of the Kyushu Dental Society*, 32, 227-260. (In Japanese with English summary.)

Tsuzaki T. (1925) The dentition in the Taiwan Aborigines. *The Journal of Korean Medical Society*, 55, 285-304. (In Japanese.)

Ueta H. (1984) Difference by sex in human tooth. *The Journal of the Kyushu Dental Society*, 38, 629-653. (In Japanese with English summary.)

Yamada E. (1931) The anthropological study of the Japanese teeth. *Juzenkai Zasshi*, 36, 469-586.

Yamada H. (1977) Factor analysis of human teeth, dental arch and palate. *The Aichi-Gakuin Journal of Dental Science*, 15, 267-287. (In Japanese with English summary.)

Yamada H., Kondo S., Sato A., and Kuwahara M. (1986a) Study of mesiodistal crown diameters in the deciduous and permanent dentitions in individuals. *Journal of Growth*, 25, 15-26.

Yamada H., Kondo S., Sato A., and Kuwahara M. (1986b) Study of buccolingual crown diameters in the deciduous and permanent dentitions in individuals. *Journal of Growth*, 25, 147-156.

Yamada H., Kogiso T., and Liao J-Y. (1986) Correlation matrices for the mesiodistal and buccolingual crown diameters of the Japanese and Chinese permanent teeth. *Journal of the Anthropological Society of Nippon*, 94, 473-479.

Yamada H., Kawamoto K., Sakai T., and Katayama K. (1988a) Inter-island variation in tooth size of the Cook Islanders, and their biological affinities with other Oceanic people. *Journal of the Anthropological Society of Nippon*, 96, 435-448.

Yamada H. and Kawamoto K. (1988b) The dentition of Cook Islanders. In, K. Katayama and A. Tagaya (Eds.), *People of the Cook Islands – Past and Present. A report of the physical anthropological and linguistic research in the Cook Islands in 1985-1987* (pp. 143-209), The Cook Islands Library and Museum Society Bulletin No. 5.

Yamada H. and Koshio Y. (2008) Mesiodistal crown diameters of anterior teeth in female orthodontic patients. *Anthropological Science* (Japanese Series), 116, 15-23. (In Japanese with English summary.)

Yamada H. and Tagaya A. (2018) Tooth size and its proportional variability in Japanese males with agenesis in permanent dentition. *Anthropological Science*, 126, 75-87.

Yamada K. (1984) A physical anthropological study of the teeth in the inhabitants of Gotoo Island in Nagasaki prefecture. *The Journal of the Kyushu Dental Society,* 38, 501-530. (In Japanese with English summary.)

Yamauchi K., Itou K., and Suematsu H. (1965) Standard for the measurements of plaster cast from Japanese young adults with normal occlusion. *The Journal of Japan Orthodontic Society*, 24, 1-7. (In Japanese with English summary.)

ʏ'Edynak G. (1989) Yugoslav Mesolithic dental reduction. *American Journal of Physical Anthropology*, 78, 17-36.

Yuen K.K-W., Tang E.L-K., and So L.L-Y. (1996) Relations between the mesiodistal crown diameters of the primary and permanent teeth of Hong Kong Chinese. *Archives Oral Biology*, 41, 1-7.

Van Reenen J.F. (1966) Dental features of a low-caries primitive population. *Journal of Dental Research*, 45,703-713.

Van Reenen J.F. (1982) The effects of attrition on tooth dimensions of San (Bushmen). In, B. Kurtén (Ed.), *Teeth :Form, Function, and Evolution* (pp. 182-203). New York: Columbia University Press.

Viciano J., Alemán I., D'Anastasio R., Capasso L., and Botella M.C. (2011) Odontometric sex discrimination in the Herculaneum sample (79 AD, Napes, Italy), with application to juveniles. *American Journal of Physical Anthropology*, 145, 97-106.

Viciano J., Lopez-Lazaro S, and Alemán I. (2013) Sex estimation based on deciduous and permanent dentition in a contemporary Spanish population. *American Journal of Physical Anthropology*, 152, 31-43.

Wajeman G. and Levy G. (1979) Growth variations in the permanent teeth of modern man. *Journal of Human Evolution*, 8, 817-825.

Walimbe S.R. (1985) *Crown dimensions among adult Muslim males of Ramapuram*, Andhra Pradesh. Inter-India Publications, New Delhi.

Weidenreich F. (1937) The dentition of *Sinanthropus pekinensis*: A comparative odontography of the hominids. *Palaeontologia Sinica*, Series D, No. 1, Whole series, No. 101. Pp. 1-180.

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