Paleopathology: Nutritional Stress
As a Measure of Environmental Stress

By

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The purpose of this thesis is to understand what kinds of societies were experiencing stresses and see what that implies about their lifestyle, environment, health, and diseases of the time. Paleopathology can be defined as the study of the evidence of trauma, disease, and congenital defects in human remains. Utilizing paleopathology can illuminate how healthy and stable a civilization may have been in comparison to other regions and may either confirm or disapprove previous notions. I will be analyzing 3-4 societies in depth, while utilizing the rest of my data for a broad comparison of stress indicators globally. With more research from other regions experiencing similar stresses, we can compare and contrast their lifestyles and hopefully gain some insight into possibly preventing such epidemics from reoccurring.

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Research Question

The aim for this thesis is to analyze combination of similar studies from several historic and prehistoric skeletal samples worldwide to provide context and discussion about stress related morbidity and mortality from throughout the globe. This thesis examined the relationship between developmental stress and environmental stresses including climate, foreign invasion, diet, SES, & urbanization. The use of multiple stress indicators is the key to assessing the true health status of populations, as there is no universal view to health between societies. The hope for this thesis is to provide an unbiased review of techniques, implications, and interpretations across multiple regions around the world for a better understanding of nutritional standards across ancient populations. These studies illuminate the bigger picture whereas infectious diseases and malnutrition still affect more of the world than chronic disease. Epidemiologists, biologists, archaeologists, & osteoarchaeologists working together to add to the bioarchaeological record lead to mitigation and aid in areas where medical technology and SES may not be able to buffer the effects. Future research can illuminate the contextual factors affecting the relationship between nutritional health and environmental stresses in order to gain a better understanding of human health overall.

Throughout my thesis I hope to emphasize perfect examples of combing multiple facets of science to achieve a better understanding of disease and the transmission of disease. There are two basic problems in epidemiology, hence the history of medicine, which have been the identification of the places where infectious diseases originated and discovery of the routes by which they travelled. For too long researchers have been relying on written documents that are supported by a small extent

of anatomical examination. This process is simply inadequate, which is why I'm arguing for a more cooperative approach towards studying diseases. The authors in previous studies and propose numerous techniques for examining human remains that will allow people to obtain reliable data. These techniques range from simply reviewing untapped parish records to utilizing immunocytochemistry to observe material stored for years. Our focus should not just be on how a disease is travelling and progressing in modern times, but also what disease loads and stressors were already active in aboriginal communities before contact. Research initiatives should include archaeological, physical anthropological, and ethno historic evidence in specific regional sequences to evaluate pre-contact disease loads.

Paleopathology can also teach us about how we perceive "violence" and what hidden biases may have written history rather than actual research. In the case of Rapa Nui, not only did paleopathology illuminate the progress of certain diseases, it also illustrated how non-violent the people of Rapa Nui actually were in contrast to what previous explorers and scientists have claimed. The "violence" of a society is still relevant to the overall health of a society and can offer deep insight into ancient populations.

Methods of Measuring Nutritional Stress

Paleopathology focuses on the health stress indicators left behind on human remains. A specimen's health can be gauged through the recording of certain infectious diseases and stress indicators. Even if only skulls are obtained for observation, "some diseases can cause specific modifications of the skeleton and thus be identified in the archaeological record" (Polet 2011). Abstract Hypoplastic defects of tooth enamel, Harris lines in the long bones, and Cribra Orbitalia have been heralded as potentially useful indicators of health conditions in prehistoric populations. In order to have stressors applicable to multiple regions and time periods, I will review the credibility of such indicators.

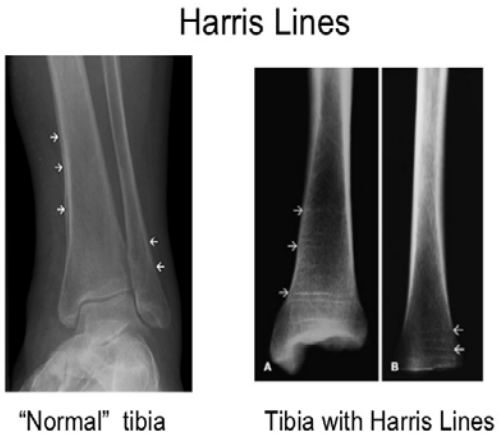

Figure 1

Harris Lines (HLs) are characterized as transverse radiopaque lines in long bones and correlates with episodes of temporary arrest of longitudinal growth (Papageogopoulou et al., 2011). This stress has been utilized to indicate nutritional status, health, and living conditions of historical populations. However, many studies have also found no association between HLs and illnesses. This is due to the fact that HLs formed earlier in life may disappear during the development of an individual, making it impossible to know with certainty the correct total number of HLs. To explore the true indications of HLs, researchers compared body measures (stature, tibia length), life expectancy, linear enamel hypoplasia (LEH) and hypothyroidism between

Figure 1 – Papageogopoulou et al., 2011 pg. 3

individuals with and without HLs (Papageogopoulou et al., 2011). This is key because in most studies, the researchers failed to correlate the presence or absence of HLs with specific stress markers and consider HLs as bone reactions to pathological or nutritional stress. Results indicate that peaks of high HL frequency were found to parallel normal growth spurts and growth hormone secretions, rather than a pure outcome of nutritional or pathologic stress (Papageogopoulou et al., 2011). In accordance with the results, it seems appropriate to discard Harris Lines as a health indicator for the purposes of this review (Papageogopoulou et al., 2011). In the same study, linear enamel hypoplasia, also referred to as dental enamel hypoplasia, was one of the variables measured in accordance with number of HLs. Teeth remain the most useful ancient skeletal specimens for detecting markers of stress, as other bone pathologies acquired during childhood are generally difficult to diagnose in adult samples, due to bone modeling and remodeling and thus the disappearance of lesions during bone growth (McHenry & Schulz, 1976; Roberts & Manchester, 2005). LEH itself is seen as a dental analog of HLs. However, there was no correlation found between the number of HLs and the percentage of LEH (Papageogopoulou et al., 2011). Many prior LEH publications utilize a variety of sources for LEH age determination, such as tooth mineralization stages by Bass (1995) (e.g. Boldsen, 2007) or more conventional methods by Massler et al. (1941) (e.g Palubeckaite et al. 2002, -Niedbala & Kozlowski, 2011).[1] However, not all projects implement consistent methodological controls when collecting LEH, which ultimately restricts addressing potential stress. When examining stress indicators in

[1] Miszkiewicz, Justyna Jolanta. "Linear Enamel Hypoplasia and Age-at-Death at Medieval (2012)

teeth, controls need to account for "age-related tooth loss and dental wear, and also identify systemic stress by comparing more than one tooth type, particularly when two or more groups are contrasted (Miszkiewicz and Jolanta, 2012)." Factors that predispose enamel defects include low socioeconomic status, low birth weight, poor maternal response to stress, young maternal age, and conditions that disrupt calcium and phosphate metabolism such as vitamin C deficiency and hyposphatemia. The presence LEH not only indicates the occurrence of stress episodes and physiological disruption but also of recovery and continued growth (Merret et al, 2016). Many osteoarchaeologists assign weaning related significance to 'peak' LEH records (e.g. Lanphear, 1990, Iregren, 1992, Ubelaker, 1992, Moggi-Cecchi et al., 1994, Wright, 1997), while some studies have shown that such a link is weak or possibly non-existent (e.g Blakey et al., 1994, Corruccini et al., 1985, Santos & Coimbra, 1999, Saunders & Keenleyside, 1999, Wood, 1996).[2] Weaning can be defined as the cessation of breast-feeding and inclusion of solid non-maternal food sources into juvenile diet.[3] However, the age at which non-maternal food sources are introduced to weaned children is highly variable among human societies as a consequence of traditional practices and cultural influences. All of these are valid concerns, however, "the degree to which such aspects would influence population-based health profiles is relatively low, as high frequency and severity of LEH would still reflect a continuum of stressful events in a child's life" (Miszkiewicz and Jolanta, 2012).

[2] Miszkiewicz and Jolanta, 2012
[3] World Health Organization Website, 2002; Griffiths et al., 2007

Early child life is important to emphasize because there are studies of skeletal stress indicators that lend further support to the hypothesis that early childhood stress results in a reduced age at death. One study analyzing tooth crown size and age at death in prehistoric Native Americans from Auerbuch, found that permanent teeth of juveniles were significantly smaller than those of adults.[4] It is suggested that environmental stressors prevent the development of teeth to their maximum size. Another study shows that smaller vertebral neural canals are associated with an earlier age at death.[5]

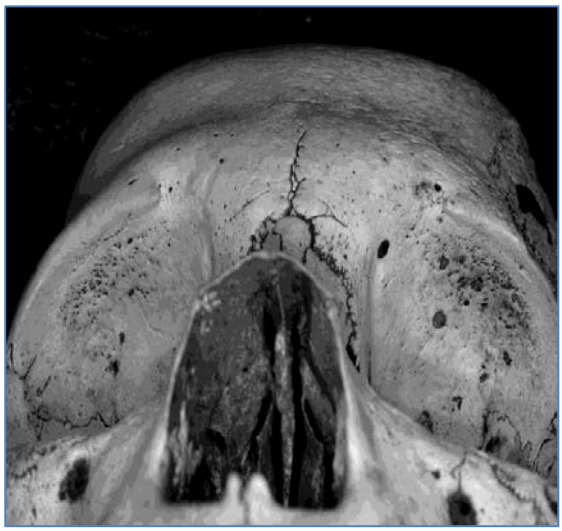

Figure 2

Cribra Orbitalia (Figure 1) is still utilized in current research, although thereis debate over the Iron Deficiency AnemiaHypothesis. This hypothesis has been widely accepted since the 1950s and the prevalence of this condition is used to infer "living conditions conducive to dietary irondeficiency, iron malabsorption, and iron loss from both diarrheal disease and intestinalparasites in earlier human populations" (Walker & P.L, 2009). However, recent hematological research shows iron deficiency alone cannot explain red blood cell production that causes marrow expansion responsible for lesions associated with Cribra

[4] Guagliardo MF. 1982. Tooth crown size differences between age groups: a possible new indicator of stress in skeletal samples. Am J Phys Anthropol 58: 383-389.

[5] Clark GA, Hall NR, Armelagos GJ, Borkan GA, Panjabi MM, Wetzel Ft. 1986. "Poor growth prior to early childhood: decreased health and life-span in the adult." Figure 2 – Walker & P.L, 2009 pg. 110

Orbitalia and Porotic Hyperostosis. In general, “Age-related changes in red blood cell production and cortical plasticity mean that cribra orbitalia probably forms between six months and four years of age in response to nutritional stress” (Watts 2013). Thus the presence of cibra orbitalia in an adult skeleton represents health issues that occurred before the age of four. One study claims that anemia-induced marrow hypertrophy is probably a common cause of cribra orbitalia, “other pathological processes such as those associated with scurvy, rickets, hemangiomas and traumatic injuries can produce sub periosteal hematomas that can lead to orbital roof lesions” (Walker & P.L, 2009). One of the alternative explanations offered was that many cribra orbitalia lesions may results from “megaloblastic anemia acquired by nursing infants through the synergistic effects of depleted maternal vitamin B12 reserves and unsanitary living conditions that are conducive to additional nutrient losses from gastrointestinal infections around the time of weaning (Walker & P.L, 2009). The following figure is a flow chart illustrating the relationships of variables related to the etiology of porotic hyperostosis and cribra orbitalia (Figure 3).

Other studies show decreased stature, depressed growth velocity, and porotic hyperostosis related to environmental stressors caused by European contact that may also be related to decreased

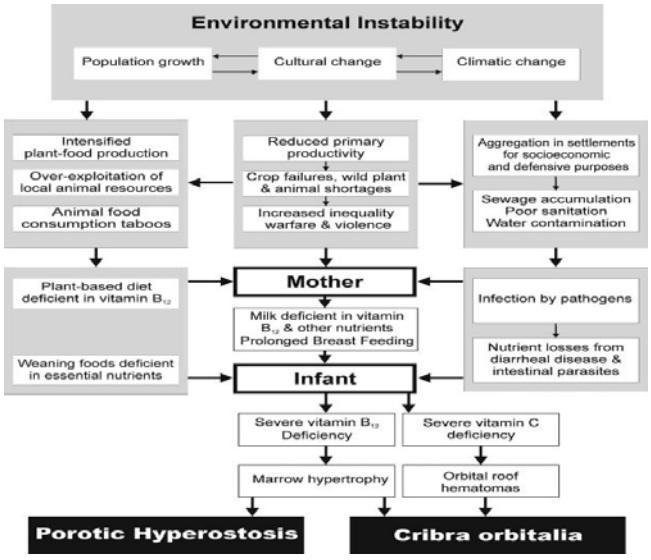

Figure 3 – Walker & P.L, 2009 pg. 113

Figure 3

longevity in adulthood (Klaus and Tam, 2009; Littleton, 2005). So if we are to measure health via mortality and longevity of a population, there are more factors involved. Cribra Orbitalia can still be utilized as a stress indicator as its etiology may be elusive but still interpreted as a sign of stress. Depending on the research team and location of certain studies, different indicators or techniques may be utilized, but cribra orbitalia and dental enamel hypoplasia will be the over arching variables for broad comparison. Both techniques essentially look at the process of development as a measure of health of a society. It seems plausible to address the overarching health of a society by examining the health of children and if they can recover from childhood stress episodes later in life. I must also pay close attention to the age differences between individuals in each sample and how each study reaches these dates of origin. This is because a 150+ years difference between individuals essentially indicates different environments. In other words, you wouldn't compare my teeth to my great great grandmother's teeth because the environment/health care was completely different. Therefore, when I have a sample ranging hundreds of years I need to treat that data with a bit of caution and perspective.

Case Studies

Among archaeologists to this day, Rapa Nui is portrayed as a cautionary tale of ecocide and carelessly consuming resources. There is no doubt that such a message should not be passed on, but this story can hardly be justified by actual biological evidence. It is the most isolated inhabited island of the Pacific, which probably factors into why it is so popular amongst archaeologists (Hamlin 1939). Unfortunately, "the disappearance of the majority of the ancestral culture holders during the slave raids and the epidemics led to the loss of most of the information relating to the history of the island and its traditions" (Polet 2011). Caroline Polet wrote a paper gauging the relative health and diet of ancient Easter Islanders based on human skeletons discovered between 1934 and 2009. The percentage of adults and children on Rapa Nui with enamel hypoplasia and the percentage with Cribra Orbitalia are in the range of variation of other histories and prehistoric samples. However, "these are much lower than European medieval populations from the 6th to the 15th century AD" (Polet 2011). This suggests that the people of Rapa Nui may have actually been healthier than people in the middle ages, disproving the notion that the islanders collapsed due to malnutrition as some previous scientists have claimed. Polet also concludes "infantile malnutrition was far from being severe as opposed to the catastrophist theories proposed by Diamond" and "the palaeopathologic study reveals, nevertheless, new cases of infectious diseases probably resulting from contact with Europeans or Americans" (Polet 2011).

A dissertation submitted to the graduate division of the University of Hawaii by John Vede Dudgeon also supports the idea that Rapa Nui was a stable environment prior to European contact by studying a total of 88 dental specimens from the island.

They utilized laser ablation inductively coupled plasma mass spectrometry of the subsurface dental enamel to test for the presence of minor and trace elements in the structure of enamel during formation. These elements in the enamel were then compared to the "elemental signature from soils and sediments that were pedogenically derived from the different volcanic flow events on the island" (Dudgeon 2008). Statistical comparisons between these two datasets were used to confirm residential stability because "the signature of the trace elements incorporated in the dental enamel during permanent tooth formation in early life [was] similar to the trace element compositional variation in the sediments of the location of recovery of the skeleton, and the skeletons [could] be chemically grouped by their location of recovery" (Dudgeon 2008).

However, with all this wealth of information available, there are scientists who have built up an exciting yet false story about the island. In the early stages of discovery and digging on Easter Island it is clear that there are some biases between the native Islander's and the Eurocentric perspective on its people. However, even with those biases put aside, there is not enough reliable evidence to conclude that Easter Island's ecosystem was fragile enough to destroy the once thriving native civilization. Diamond's claims that the natives "had the misfortune [of] living in one of the most fragile environments, at the highest risk for deforestation, of any Pacific people" is entirely an assumption, which leads to the cautionary tale that "of a society that destroyed itself by overexploiting its own resources" and therefore, a cautionary tale to every modern society (Diamond 2005). Even though there is a positive message in this

fabricated story, in reality, deforestation is blamed for the population collapse that occurred as a result of Old World diseases being introduced to the native population.

In other words, Rapa Nui is not a tale of ecocide, cannibalism, or warfare, but really a story of brilliant engineering and survival. Perhaps Mr. Hunt said it best when he claimed "They did exactly the right thing for that island...they avoided collapse, on a small poor, and isolated island. They are the story of remarkable success. The only collapse came with the diseases introduced from the outside world after 1722 and as a result of it".[6] Paleopathology, in this case, has added to the archaeological record of the region.

The sweet potato connects Hawaii and Easter Island. This incredible human link between lands 4000 miles apart is a fair enough reason to compare these regions. We can now examine Hawaii, as Polynesians were the first people to arrive around the fourth and fifth centuries A.D (Pietrusewsky 2014). Pietrusewsky and M.T. Douglas studied the skeletal and dental biology of twenty-four sets of human remains disinterred in 1988 from a late historic Hawaiian cemetery in Kailua-Kona. This is an ideal sample to compare to Rapa Nui because the specimens are generally from the same time period as Polet's sample. The ideal situation is that a "cemetery reflects the demographic profile of the community which contributes to it", but this seems to be a unique sample because of the large number of fetal remains (Pietrusewsky 2014). Paleopathological observations of the remains include "a low dental caries rate and slight periodontal disease reflecting the young age-at-death of the sample" (Pietrusewsky 2014). They did find evidence of metabolic and nutritional stress, more specifically, Cribra Orbitalia.

[6] YouTube National Geographic Live https://youtu.be/rut16-AfoyA

However, this was only observed in the remains of a single middle-aged female. Enamel hypoplasia was also present in 15% of the permanent teeth (Pietrusewsky 2014). Already we can see similar diseases present in two different environments that contained the same origin of people. The similarities also support Polet's claims that the percentage of people in Rapa Nui who had hypoplasia and Cribra Orbitalia were not severe in comparison to other regions, such as Hawaii in this instance.

Paralleling Hawaii with Rapa Nui, its not an unfair suggestion that Europeans may have simply introduced a variety of infectious diseases that could easily devastate a population of isolated island inhabitants. They discovered that enamel hypoplasia is more common in teeth from historic skeletons than in those from pre-contact times. The comparative data suggests "these indicators of general stress occurring at early ages were more common in contact times than in prehistory" (Pietrusewsky 2014). However, for Cribra Orbitalia, no significant difference in pre-contact and post contact adults was observed. They also found an individual female that has vertebral lesions consistent with tuberculosis. This is important because no signs of skeletal tuberculosis were recorded before, which may reflect "the arrival of new diseases associated with contact prior to the noticeable changes in mortuary practices" (Pietrusewsky 2014). There is only one published case of possible treponematosis from Hawaii prior to Captain Cook's arrival, and DNA from this skeleton reveals "the nine base-pair deletion seen frequently in Asians and Polynesians" (Pietrusewsky 2014). The chapter reveals significant differences between pre-contact and post contact skeletal remains for a variety of health indicators. Overall, the investigation illustrates deterioration in health. The study also states that certain infectious diseases, "such as tuberculosis and

treponematosis (yaws and syphilis), traditionally assumed to have been introduced to Hawaii with Western contact are now either confirmed or challenged by the osteological record" (Pietrusewsky 2014).

As a stand-alone study, this paper follows the typical pattern of a paleopathologic study. It ultimately points to the underlying issues facing this particular sample, which was the introduction of new infectious diseases coupled with lower fertility. Researchers also mark the transmission of certain diseases, making this study valuable to the medical community. One small detail that may easily be overlooked is the fact that native scholars were referenced and utilized in this study. This is not always the case, and "outsiders" digging up graves of native people's may be troublesome for researchers who need permission for such research. It works in everyone's best interest to recruit the guidance and input of local scholars as they provide insight into history with all the cultural nuances being addressed as well. This case also challenges the historical perception of these early European explorers, as they are usually revered in their homelands. However, when looking closely at the natives, a serious decline in overall health due to new infectious diseases is most commonly the case. Although reliability may be in question, comparing the skeletal sample to surrounding samples is the ideal method when researching a region, as even settlements that are near each other may have a number of factors and/or lifestyle habits that contribute to completely different health profiles.

The researchers attributed the slight increase found in the post-contact to more stress during childhood rather than survival, once again pointing to the significance of childhood stress .In most cases, methodological differences in recording and reporting

frequencies limit the use of other researchers' data. However, this study emphasizes how in Hawai'i "we are fortunate that workers are increasingly adopting a common standard for collecting osteological information (Pietrusewsky 2014)." Oddly after stating this fact, the researchers state that they will only emphasize the data in this particular study and not others due to "incompatibility issues". The inclusion of an infectious diseases section provides health-related insight that can be helpful towards modern medicine and should be included in the normal agenda of paleopathology.

Another comparable case study to Hawaii and Rapa Nui would be to look at the health of the ancient Mariana Islanders. I include this study because it focuses more on the environmental factors that may have influenced the islander's health in prehistoric conditions and re-examines the question of inter-island variability in health and lifestyle of the natives. The native people called the Chamarro were hypothesized to have higher stress levels on smaller islands, as smaller lands are more susceptible to "environmental perturbations which would affect human health because of smaller land mass, remoteness, lower rainfall, freshwater lens, slightly cooler temperatures, narrow and non-continuous fringing reefs, earthquakes, volcanic eruptions, and sea-level fluctuations" (Pietrusewsky 2014). The four islands in question include Tinian, Saipan, Rota, and Guam. These islands are located in the southern area of the archipelago, and are also the largest islands, which indicates why people preferred to live there in the past and presently. As far as the people go, it has been suggested that the northern Philippines is a possible source of the earliest human settlements. However, recent DNA evidence suggests that the Mariana Islands were initially settled approximately 4000 years BP by a small group of people from Southeast Asia. This initial population

remained genetically isolated until approximately 1000 years BP when another wave of migrants arrived. Pre-contact agriculture and economies included reliance on "cultivated tree and root crops typical of tropical island environment such as coconut, banana, breadfruit, taro, yam, and possibly rice – all foods high in carbohydrates" (Pietrusewsky 2014). The diet was also rich in marine sources such as fish and shellfish. Along with agriculture, the Chamarro relied on hunting and gathering tactics to catch birds, fruit bats, monitor lizards, turtles, and crabs. Taking the natives geographic landscape, diet, and social background into account, I can now analyze the skeletons with a broad perspective in mind. The main stress indicators that were found on this island suggest *cribra orbitalia*, dental enamel hypoplasia, stature, long bone fractures, spondylolysis, tuberculosis, and leprosy (Pietrusewsky 2014).

Previous research suggested that the precontact inhabitants of the smaller islands, such as Rota, Tinian and Saipan, were less healthy than those from Guam, the largest Island. However, tests of statistical significance in the frequencies of 13 indicators between the four largest islands revealed, "the majority are not statistically different" (Pietrusewsky 2014). The results suggest greater similarities in health and lifestyle in skeletons from Rota and Guam in contrast to those from Tinian and Saipan. Unexpectedly, several frequencies of indicators from Rota, the smallest island, were similar to those from Guam, the largest island. The proximity of the islands may explain this finding, more specifically, a formation of large island/small island partnership.

This case is intriguing as it goes against what previous research indicates, which is that smaller islands struggling more than larger islands. The study really focuses on possible sex differences, a variable that may be influential in discerning the health

profiles of a society as men and different are biologically different and quite possibly may react differently to stress. Women's health is a hot topic in the U.S right now, as most of the current treatments available for modern illnesses are based on research conducted only on men, as it was perceived to be too harmful for women. This ultimately resulted in treatments/procedures that are less efficient or unhelpful to women. Utilizing paleopathology, the research side of medicine could benefit greatly from sexual differences indicated when observing health insults on the body. By doing so, they can better strategize how to account for these differences when progressing the field of women's health research. As far as this particular paper goes, sex differences were discovered but they were not statistically significant. However, that does not mean that these differences should not be observed in other studies, which may look at different indicators/environments. The paper utilizes 13 different health indicators, which seems to be a bit too broad for the purposes of gauging a society's health. All 13 indicators must have previously established credibility, and there must be a logical basis for why these are chosen. The researchers present fair interpretations of their results across all indicators yet spend little time establishing the reliability of each one.

Although much more research is needed, this study offers some answers to questions regarding intra- and interisland variability in skeletal indicators of health, temporal changes in health, and variability by sex and age. This study is also comparable to the Pietrusewsky's Hawaii analysis of pre-contact and post-contact as the natives of the Mariana Islands faced a similar stressor. However, the researchers only focused on signs for treponemal infection instead of including others. Uneven and small sample sizes make it difficult to reliably view this skeletal series as representative of the

population. Any stress indicators involving dental health is difficult to interpret, as differences seem to be related to the use of the betel nut. The influence of the chewing of betel is debatable as some believe it protects from dental caries while other research illustrate how periodontal disease and dental calculus may be greater in chewers (Chatrchaiwiwatana 2006). A WHO study analyzing the affects of betel chewing found that there are multiple confounding variables such as "level of oral hygiene, dietary factors, general health, and dental status".[7] Thus, results regarding dental pathology/indicators in this paper must be approached cautiously, but will not affect LEH results as these lesions form during early childhood and the chewing of the betel nuts as adults would have no effect. However, the methods chosen by these researchers are taken from Pietrusewsky's 2002 paper, which provides a reliable baseline for comparison, at least to Pietrusewsky's and Douglas' work.

From the islands we move to examine a particularly interesting source of skeletal remains dating from 17-19th century Caribbean slave population in Barbados. After slavery ended in the British Empire from the middle of the 17th century to 1834, the wealth of Barbados depended on the agricultural economy of the tens of thousands of slaves of African birth or descent. Thus, by the early 19th century, a much greater percentage of the slave population was native-born. This contrasts to earlier periods in which a greater percentage of the slaves were African-born and thus African cultural patterns were also followed to a much greater extent. According to researchers, "This

[7] International Agency for Research on Cancer (IARC). 2004. *Betel-quid and Areca-nut Chewing and Some Areca-nut-derived Nitrosamines, Volume 85.* Lyon, France: Monographs on the Evaluation of Carcinogenic Risks to Humans.

population is probably unique in terms of environment, nutritional deficiency and other severe environmental stresses, and (especially) association with historical resources that might allow more specific correlation of stresses with hypoplasia chronology" (Robert S 699). The specific site chosen was a slave cemetery at Newton plantation because of the availability of historical documents as well as the permission of excavations in relatively undisturbed contexts. Researchers concluded that "Newton typified medium-to large-scale Barbados sugar plantations of the slave era; thus the analysis of Newton's slaves may be generalized to other plantation slave populations on the island" (Corruccini 1985).

Of the 103 individual specimens observed with teeth, 56 were hypoplastic (54.5%). This is the earliest and largest excavated group of African and African-descended slaves reported from the Caribbean and North America. The historical evidence indicates Caribbean slaves experienced nutritional deprivation, which would cause severe developmental disruption. From this data, researchers concluded that hypoplasia was most likely to occur around age three for any given individual slave surviving infancy. The tendency for more numerous and serious hypoplasia's to occur late in calcifying teeth may possibly be related to a late weaning period in Caribbean slaves. Documentation illustrates how two Barbados-born medical doctors who practiced among plantation slaves alluded specifically to the risks of the weaning period. One doctor in particular attributed high infant mortality to "the highly improper food mothers gave their children" as well as "the period of nursing the child being protracted to an age when it is both injurious to the mother and infant" while the other doctor also assigned the cause for high infant mortality to housing conditions

(Corruccini 1985). The tendency for hypoplasia to form 3-4 years in postnatal surviving Barbados slaves is late in comparison with other groups studied in this paper such as Chicago Whites and medieval Swedes. With the exception of medieval swedes, the Barbados slave total hypoplasia distribution appears less pronounced peaks or leptokurtic.

The strength of this paper lies within the fact that it is a snapshot of a slave population. This ultimately represents a "negative control" in the sense that it should be one of the poorest if the not the worst health profiles on the spectrum. This is also an interesting case in regards to LEH, as typically the high rate of LEH would be attributed to weaning children too early rather than taking too long as in the case of the Barbados mothers. For a deeper understanding of the health implications of LEH alone, this study provides an interesting counter perspective to the weaning hypothesis most commonly accepted in current literature. This case also provides insight as to how a colonial economic system affected the health of the oppressed that carried on the same line of work, even when the colonizers are gone. The deeper embrace of African culture by the newborns of the previous enslaved generation did not adequately buffer the health insults, and may in fact, have exacerbated it instead. The testimonies of two medical doctors who lived alongside the sample being studied gives this paper a unique window into the not only the underlying issues facing the people, but also the medical perspective embraced by local physicians at the time. It would be a fascinating comparison to compare the medial diagnoses of these two physicians to two modern day physicians who practice in the same area today. This case is a perfect example of

how Paleopathology can open up new avenues of further study that can add value to multiple scientific and medical fields.

The methods of this paper towards LEH is interesting as they hone in on the central tendency of 3-4 years for the formation of hypoplasia's. They analyze the percent concentration between 3-4 years and the residual occurrences at 4+ years compared to other reported populations. The assumption here is that hypoplasia peak is related to the post-natal time of maximum environmental/metabolic stress on children in non-industrial societies. The age of hypoplasia formation in Barbados slaves is late whereas "Chicago Whites peak at 0-1 year, composite prehistoric Amerinds and Missouri Mississippian Amerinds peak at 2-3 years, and Dickson Mound combined pre-agricultural and agricultural Amerinds and medieval Westerhus Swedes peak at 2.5-3 years" (Corrucini 1985). One downfall of this study is the lack of demographic information regarding the skeletal sample, to which the researchers admit is "unavoidably subjective" (Corruccini 1985). The classification of enamel hypoplasia is based on modifications of earlier sources, which include three different forms of hypoplasia. Although this particular method is somewhat based on previous work, the modifications make the data difficult to compare to others. However, the true value of this study is not seen through comparison, but more so as an individual unique study analyzing factors specific to these people in this time period. It is important to note that the weaning hypothesis regarding LEH is supported, as this is the first study observing a specific population wherein hypoplasia concentration is shown to occur the year following a historically documented time of weaning.

The next region of the world we will examine will be Asia. More specifically, regions include Indus Valley civilization, Southeast Asia, Northeast China, and Taiwan. The Indus Valley thrived 4000±5000 years ago in what is now Pakistan. The civilization apparently "possessed a highly specialized and functionally integrated economy, centralized bureaucratic institutions and a large population base, as well as its own writing system, a uniform system of weights and measures and consistent vessel forms and iconography (Lovell 1997)." The sites of Harrapa, in the north, and Mohenjo Daro, in the south, were considered twin capitals. The sample studied was obtained by the University of California (Berkeley) in 1987 and 1988. The skeletal remains came from primary burials in the Harappan cemetery and there appears to be limited variability in "status-associated grave goods", indicating that no burials exhibit the same richness of

Figure 4

Figure 4 – Lovell 1997 pg. 117

elite burials such as in ancient Egyptian or Mayan civilizations (Lovell 1997). The site contained 92 individuals, however, only 29 crania were preserved for assessment due to poor preservation. Only two of the 29 crania recovered displayed cranial lesions of porotic hypersostosis, suggestive of chronic anemia. However, in a sample of 40 individuals obtained from Mohenjo-Daro, seven individuals (18%) displayed porotic hyperostosis, and both children and adults were affected. It was also reported that 25% of several hundred individuals that comprise a total human sample from various sites of the Harappan civilization contain vault lesions. Although nearly one third of the 92 individuals at Harappa displayed pathological lesions, enamel hypoplasia was exhibited in 72% of permanent dentitions. However, enamel hypoplasia was not observed in any skeletons from Mohenjo-Daro. Researchers conclude that the etiology of anemia, which was already debated as the main source of cribra orbitalia, may be best explained by multiple factors in each physical and social context. The data indicates that anemia was more prevalent in Mohenjo-Daro. This location can be categorized as a highly urbanized center which often "exhibits high frequencies of acquired iron deficiency due to the prevalence of infectious diseases caused by contaminated water supplies and close contact of inhabitants" (Lovell 1997). The lower prevalence in Harappan may be attributed to a good nutritional base in a diverse ecological setting, and few gastrointestinal and other infections due to high standards of personal and community hygiene (Lovell 1997). The iron deficiency anemia may alternatively result from dietary inadequacies of intake or absorption or genetic inheritance. Nutritional deficiencies are an unlikely explanation as conditions such as Rickets and Scurvy are rare in South Asia. In this sample in particular, the Harappan skeletons indicate episodic morbidity, but

reflect acute rather than chronic stress because this sample is not associated with high frequencies of porotic hyperostosis (Cribra Orbitalia) or periostitis.

This paper hones in on the affects of transitioning from a primarily nomadic lifestyle to a more sedentary, urbanized society. One would assume that the technological advances implemented would reduce stress, but this does not seem to be the case. However, the fact that the sample indicated acute rather than chronic stress implies that it was not necessarily sedentism that deteriorates health in this scenario. There is not solid obvious factor in this study that explains the results, but the standards of hygiene is a logical conclusion for the researchers to make. This parallels medieval Europe, which struggled with hygiene, creating the perfect breeding grounds for diseases to flourish. In this literature review, this is perhaps the most advanced civilization included in the analysis, and it would not be unreasonable to compare to modern day civilizations as well. The established society, thriving on new technologies and systems of order, acts as a basis of comparison to either other greatly advanced civilizations or any societies today. This allows researchers to really narrow and focus their efforts on the confounding variables interacting with the health of peoples who, in theory, should be healthier than before such advances.

This paper heavily focuses on the probable causes of anemia through physical, sociocultural, and environmental evidence. However, they come to the conclusion that many factors are involved, hardly a surprise. This case in particular may be difficult to compare to others simply because of all the possible explanations offered. There would have to be some similarity between regions, such as an endemic or environmental disaster, to provide a basis of comparison. In regards to Mohenjo-Daro, environmental

differences related to Indus flooding and malaria may explain the relatively greater frequency of porotic hyperostosis. Going with this theory, researchers claim that there may be a genetic anemia present at Mohenjo-Daro. The reasoning behind this theory is based off the geographic distribution of inherited abnormal hemoglobins and widespread malaria in South Asia. However, the scarcity of skeletal remains provides no evidence to confirm this interpretation. The Pakistani state of Sind, where Mohenjo-Daro is located, harbors mosquito vector *A. culcifacies, which* feeds primarily on cattle but also humans if cattle are scarce. It seems humans are the primary food source in urban areas where the mosquito breeds, but it is still a stretch to assume that this endemic was in full swing in the past because it is presently. This paper does have medical value as medical historians were previously unconvinced of malaria until Roman Times[89]. The discovery of fossilized remains of several types of blood-sucking mosquito expose their existence in the Old World for over 60 million years. This is what led researchers to theorize that "irrigation practices and the ponding of water after river flooding may have helped form breeding places for malaria-bearing mosquitos and endemic malaria may have followed from the commencement of sedentary subsistence technologies in South Asia (Lovell 120)." Regardless of the legitimacy of this interpretation, this discovery adds to the pathological history of malaria in the Old World and benefits the medical community. Although no definitive answer was presented, the researchers thoroughly consider all pathogenic, environmental, and societal factors that could logically contribute to the big picture overall. Ultimately, this

[8] Ackernecht, E. H. History and Geography of the Most Important Diseases. New York: Haffner, 1965.
[9] Henschen, F. The History of Diseases. London: Longmans, 1966.

paper provided more definitive insight into the migration patterns and effects of malaria than the causative agent(s) postcranial lesions.

We will now direct our attention to Northeast China, honing in on the Dongbai plain, which acts as the boundary between sedentary agriculturists and nomadic pastoralists. Examining this region allows us to explore the relationship between stress exposure, subsistence, and cultural complexity. The human remains of one study were recovered from the upper level of the Houtaomuga site on the Dongbie plain. These specimens date back to the Hanshu II cultural period (2250-2050 BP) (Merrett 2016). Results show overall 72.73% of the individuals examined (40/55) exhibited Linear Enamel Hypoplasia (LEH). In adults alone the prevalence is 96.8% (30/31). These prevalence's are similar to those of Hokkaido Jomon, slightly higher than the two other Jomon data group, and much higher than those observed in Inui and Neanderthal foragers. The follow table shows comparison across the regions (Table 1).

Archaeological context, time period, and LEH prevalence of Jomon[a], Point Hope Inuit[b] and Neanderthal[b] in comparison with Houtaomuga (HTMG).

Site/Group	Date (Years BP)	Subsistence	N (Individuals)	LEH (%) (by Individual)
HTMG	2250–2050	h/g/millet agriculture	55	71.4
Hokkaido	4000–2300 Late/Final (LF)	Foragers/marine mammals and fish	23	73.9[a]
CoastalLF	4000–2300 (LF)	Foragers/fewer marine mammals and fish than Hokkaido Jomon	69	61.1[a]
Inland	4000–2300 (LF)	Foragers/fewer marine mammals and fish than Hokkaido Jomon, more C3 plants than coastal		
Point Hope	700–300	Foragers	21	38.1[a,b]
Neanderthal	130,000±10,000	Foragers	74	37.8[b]

Table 1

Table 1 – Merrett et al, 2016 pg. 5

Among prehistoric populations, hunter-gatherers live to approximately 21.6 years (SD =2.1 years), horticulturalists live to approximately 21.2 years (SD=3.9 years), and agriculturalists live to about 24.9 years (SD=8.5 years) (Wolfe 2014). The distribution of LEH across age categories by individual varies significantly. High LEH was also observed in Hokkaido Jomon (73.9%, N=23), both Coastal and Inland Jomon (61.1%, N = 69) foragers from Japan, and in south Asian Mesolithic foragers from northern India (83.3%, N=57) (Merrett et al, 2016). This contrasts with past forager and modern sample in which the proportion of LEH is much lower at between 6-49%. What is particularly interesting about the Houtamuga site is that almost all who survived to age 4 years (36/37) had experienced at least one severe stress episode. According to researchers, if the older women without LEH (1/13) had lost her LEH due to 50% tooth crown attrition, then everyone at Houtaomuga who survived past the age of four years had experienced substantial stress episodes in childhood. Therefore, the children of Houtaomuga represent a highly stressed and vulnerable faction of the society (Merrett et al, 2016).

Regardless of the high prevalence of LEH, there is high survivorship data that includes "timing of stress episodes relative to developmentally critical times, pathogen-specific factors, and archaeological/cultural context. Perhaps stress events did occur in critical times during development and cultural buffering may have been at least partly effective. Or perhaps stressful events did occur during critical times but subsided later in life so that later survivorship was not compromised. Stress duration was not correlated with subsistence strategy, since "Houtaomuga inland hunger-gatherer-fisher-millet cultivators exhibit similar mean duration to coastal Hokkaido Jomon foragers,

significantly longer duration than inland Jomon foragers, and significantly shorter than the Coastal LF Jomon foragers, Inuit, and Neanderthal hunter/gatherers (Merrett 2016).” Location relative to coastal resources also does not appear to show any relationship to stress duration, indicating inland HTMG and coastal Hokkaido as similar (Merrett et al, 2016).

This high prevalence of LEH is astonishing for a time period that was politically stable. It is possible that climatic conditions juxtaposed with cultural factors such as cultural complexity may have an impact on population exposure to stressors. It is suggested that the facilitation of control of resources may have predisposed the population with periods of climatic stress, crop failure, and food shortages. Modeling data using the climate model NCAR CAM2 indicates that the precipitation in Northeast China has been driven by the East Asian summer monsoon system. Slight changes in climate would also be predicted to result in crop failure every 3 or 4 years. The fact that almost all of the individuals of the population managed to survive enough to develop LEH and recover illustrates strong resilience, which can be argued as a genetic component but is most likely due to a diversity of subsistence practices, cultural buffering mechanisms, climate fluctuations, and adaptive phenotypic plasticity. The broad-spectrum economy may have increased immune competence and reduced stress episodes, thus compromised survival later in life did not occur. It can also be inferred that during years of reduced food resources, there may have been more communication and interactions with other communities, thus increasing potential for pathogen exchange. Factors relating to economic, social, cultural, biological and pathogen loads juxtaposed within a setting of climate instability contribute to the high LEH prevalence

and variation. This complex milieu of relationships highlights the importance of site-specific context when evaluating the implications of LEH prevalence and other stress parameters amongst human remains (Merrett et al, 2016).

Researchers did not choose this region to study in order to prove a certain theory or the prevalence of certain factors, but because these people played important roles in the formation of Chinese civilization. To put this in perspective, the previous paper (Lovell) veered more strongly to the medical side of paleopathology. This paper leans more towards the archaeological side, with the goals of truly understanding the people rather than the health of the people. This paper truly embraces all the potentials of paleopathology by considering all possible factors that could be involved in this case. Unlike most other papers, this one does not seem to follow a predisposed set of methods directly aimed to prove a certain theory. Rather, this group of researchers seems to embrace an open mind whilst conducting research. This makes for a much longer debate as to what the true causes are in regards to this sample's health, but it is a more thorough analysis of the situation which holds more value in the end.

This paper is also similar to Lovell in the sense that Lovell attributed a myriad of factors to postcranial lesions and Merrett also lists multiple elements to the development of LEH. Unlike the previous studies, this study interprets the presence of LEH as not only an indicator of stress episodes and physiological disruption, but also as recovery and continued growth. This paper aims to narrow down the number of stress episodes, calculated as ranging from 17 to 28 days at the low end to 98 to 154 days for the longer duration events, and compare this to other regions. This is a good sign, as these results will have more credibility due to common data collection techniques.

Similar to the Mariana Islands paper, climate is examined as a possible influence of stress for this time and region. It's worth noting that this paper also includes adults, and not just LEH in children. However, the minimum standard for being included in the study was that each skeleton had to have at least one anterior tooth, with only 4 out of 55 at this minimum level. This means that there are significantly less teeth present per individual, and may skew the reliability of results. In other words, it may be difficult to compare this study with a sample of 55 skeletons because not all the teeth are available. They detect defects utilizing methods presented in Skinner et al., (1995) and Armelagos et al. (2009), a methodology not referenced in the previous studies. Regardless of what methodology is quoted, the researchers make numerous compromises and minimum standards due to the poor condition of the specimens overall. At the same time, these modifications are needed to obtain meaningful results and counteract all the obstacles inherent in the sample. This makes this data set extremely difficult to compare, but that does not mean it offers no insight of value, results will simply remain credible for this particular region and time. They do estimate duration of episodes, similar to Merrett, ranging from 16 to 102 days. The sample at Houtaomuga showed the highest prevalence of LEH observed so far in this review even when taking into consideration and the political stability and reliability at the time. These factors were not enough to buffer the stress, which seems odd, as previous studies have linked LEH to nutritional deficiencies[10][11]. Perhaps the more valuable branch of the paper is in regards to climate.

[10] Sweeney, E.A., Saffir, A.J., de Leon, R., 1971. Linear hypoplasia of deciduous incisor teeth in malnourished children. American Journal of Clinical Nutrition 24, 29-31.

[11] Masumo, R., Bårdsen, A., Åstrøm, A.N., 2013. Developmental defects of enamel in primary teeth and association with early life course events: a study of 6e36 month old

Previous research has shown that climactic changes have preceded changes in human societies before, sometimes as serious as societal collapse (Mayewski et al., 2004; Weninger et al., 2009; Hsiang et al., 2013). Previous examples include Mesopotamia, Thailand, and Peru (de Menocal, 2001; Wu and Liu, 2004). This paper emphasizes the importance of site-specific context in evaluating the meaning of LEH prevalence, an approach that should be adopted by all future studies.

The next study involves Taiwan, which includes specimens between the early Neolithic Taiwan (Nankuanli East site (c. 5000–4200 BP)) and Iron Age Taiwan (Shihsanhang site (1800–500 years BP), including skeletal series from surrounding regions of East and Southeast Asia. The Nankuanli site is located the Tainan Science Park in southwestern Taiwan, while the SSH (Shihsanhang site) is located on the north-western coast of Taiwan near the mouth of the Danshui River. The Nankuanli site contributed

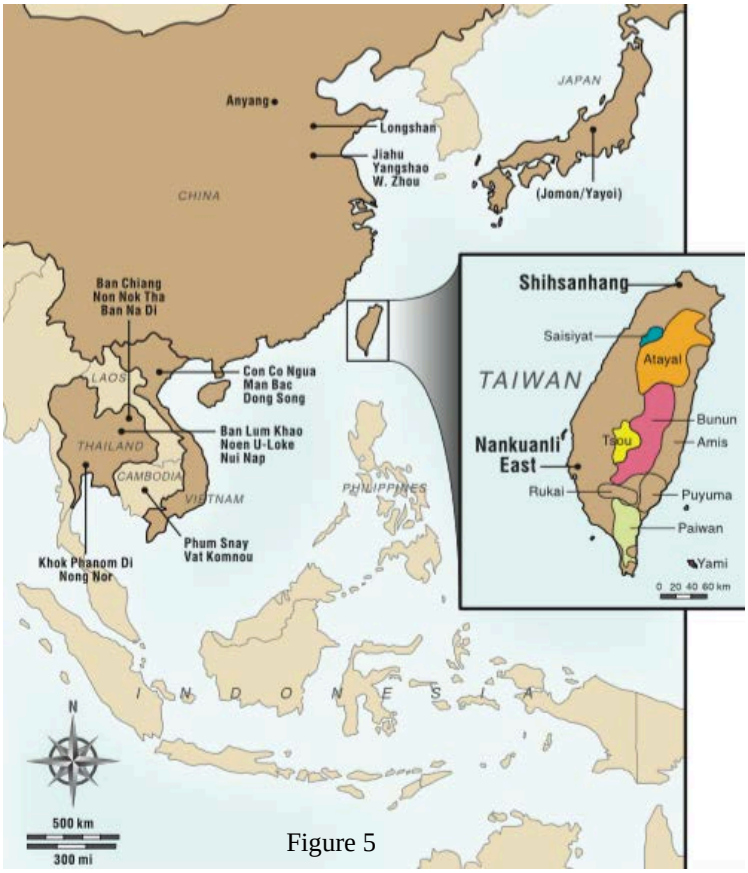

Figure 5

Figure 5 – Pietrusewsky et al, 2016 pg. 119

children in Manyara, Tanzania. BMC Oral Health 13 (21), 11. http://www.biomedcentral.com/1472-6831/13/21.

twenty-four of the most complete adult burials representing 14 males and 10 females to this study. Twenty-three of the best-preserved and most complete adult skeletons from the SSH site (Pietrusewsky and Tsang, 2003) are used in the present study.

Based on previous research (Cohen and Armelagos, 1984; Larsen, 2006; Cohen and Crane-Kramer, 2007; Temple and Larsen, 2013), it is predicted that the livelihood of Iron Age Taiwan will be associated with an increase in systematic stress and certain dental indicators of health when compared to the early Neolithic communities in Taiwan. Thus, frequencies of childhood stress (CO and LEH) and dental pathology are expected to increase from early Neolithic to later Iron Age Taiwan. This studies also observes CO lesions and LEH linked to iron deficiency anemia as a result of nutritional deficiencies, especially during early childhood, infectious diseases, gastrointestinal parasitic infections leading to infant diarrheal disease, as well as hereditary hemolytic anemia's.

Contrary to expectations, results show the frequency of LEH significantly lower in the Iron Age skeletons (37.1%) (Pietrusewsky et al., 2013) and the expected increase in dental pathology (AMTL, caries, and alveolar defects) in the Iron Age skeletons was not confirmed. Few differences of systemic stress indicators between the Neolithic and Iron Age Taiwan series were found, suggesting there is no increased reliance on cereals or change in emphasis between millet and rice. Instead, researchers propose that the subsistence base remained very broad, including marine, riverine and terrestrial resources. They also suggest a decline in childhood stress over time that may be linked to improvements in food- processing techniques, better weaning foods, and less contamination of food/water in later Iron Age Taiwan (Pietrusewsky et al., 2013).

The researchers run into an issue comparing the prevalence of CO among the locations, suggesting differences in the methods of recording this stress indicator. This is due to a lack of standardization in reporting data in the studies conducted by different researchers. Regardless, their numbers show some of the highest frequencies of CO in the region were collected from early skeletal series from Vietnam and the Khok Phanom Di series from Thailand. While on the other hand, some of the lowest frequencies of this indicator are skeletons from sites in Northeast Thailand, and early and middle Yangshao skeletons from China. The frequencies of CO in the NKLE skeletons are most similar to the skeletal series from China and Thailand. As reported in Pietrusewsky et al. (2013), LEH is moderately elevated in the NKLE series, suggesting that the early Neolithic inhabitants of Taiwan experienced relatively high levels of physiological stress during childhood.

This paper also compares a more active lifestyle to a more advanced, yet sedentary lifestyle. However, this is unlike Northeast China in the sense that it is the same location over a span of time rather than two different societies coexisting during the same era. The researchers ultimately conclude that the lack of difference is due to a broad diet, ultimately pointing to the fact that the natives basically satisfied their nutritional needs early on and didn't feel the need to change core elements, regardless of the new technologies at hand. However, the way foods were processed and prepared were improved which would have a slight impact on results, but not significant enough. The paper seems to have tunnel vision as it focuses on the nutritional profile of the natives and not delving too deep into the cultural, climatic, or political atmosphere. It does reference other close areas for comparison, which should be included in every

paper as it better represents the population.

Unfortunately, it is hard to consider these comparisons due to the lack of standardization of recording techniques, a reoccurring problem in these studies. On the other hand, research methods are based off of Pietrusewsky et al. (2013), which provides a basis for comparison although it is no surprise that the researchers are using the same methods they've already established themselves. Hopefully this is a sign of confidence in techniques and not blind obedience to what seems to work without taking into consideration other research techniques. This study found very little differences in contrast to the people of Northeast, who also went through a similar transition in lifestyle. Similar to the natives of the Mariana Islands, chewing the seed of the areca palm (*Areca catechu* L.), which happens to actually be incorrectly referred to as the betel nut. It's amazing to find this cultural practice spanning from SouthEast Asia to the Mariana Islands. This nut is a confounding variable regarding dental defects, however, because both peoples engage in this practice, it would not be unreasonable to compare these two data sets. However, this study looks at cribra orbitalia and not LEH in particular. This study is meant to be observed as a unique, isolated case, as the paper even states " there are limited comparative data for skeletal series outside of Taiwan that overlap temporally and spatially with those from NKLE and SSH" (Pietrusewsky 2016). This study also seems to focus on the differences between males and females, a category of analysis not emphasized in the previous studies except for the Mariana Islands paper.

The next region of examination will be Europe, in England and the UK. Linear Enamel Hypoplasia and Age-at-Death was recorded from medieval human skeletal

remains recovered at the St. Gregory's Priory and nearby Cemetery in the Northgate are of Canterbury (Kent, UK). This monastery was established in the 11th century and functioned until early 16th century (Miszkiewicz & Jolanta, 2012). This structure was established for clergy to aid the sick and provide burial services for financially disadvantaged members of society. According to historical and archaeological textual records, the individuals buried at the priory (Priory n=19) were of a higher socioeconomic status (SES) than those buried in the cemetery (Cemetery n=30) (Miszkiewicz & Jolanta, 2012). This presents a much more controlled and limited comparison between socioeconomic status rather than a sample that is representative of the entire region, providing a controlled view of how SES can affect health.

Researchers chose to adopt Ried and Dean's (2000, 2006), work on tooth formation times based on histological examinations that take into account hidden (appositional) enamel (King et al. 2002) in order to obtain reliable data regarding LEH formation age (Miszkiewicz & Jolanta, 2012). Results indicated that hypoplasia was recorded in the majority of individuals, with only two samples from the cemetery and four samples from the Priory displaying unaffected dentition. Both groups were almost completely affected by LEH, but Cemetery individuals displayed significantly higher LEH frequencies, implying that they experienced heavily disrupted health during childhood. Age-at-death estimates differed significantly between Cemetery (mean = 39.8 years) and Priory (mean = 44.1 years) samples (Miszkiewicz & Jolanta, 2012). The study supports the notion that a low SES can negatively affect an individual's wellbeing. In this case in particular, low SES disrupted enamel formation during childhood, and consequently a shortened longevity. SES and its affect on health and

development in children in particular is a current hot topic for current psychology research. By utilizing paleopathology and examining this ancient sample, researchers have proved SES is a reliable indicator of stress in a time period before psychology was even an organized, recognized, and formulaic practice.

This paper takes some time to mention previous studies of LEH in population and how not all projects implement consistent methodological controls. The example provided is a study that increases sample size by choosing only one tooth, a process we have already seen in the Haotaomuga paper. Miszkiewicz provides a standard of comparison in the following sentence: “When examining stress markers registered in teeth, it is indeed of importance to assign as many methodological controls as possible to account for age-related tooth loss and dental wear, and also identify systemic stress by comparing more than one tooth type (e.g. King et al., 2005), particularly when two or more groups are contrasted (Miszkiewicz et al., 2012).” However, this study is the first, to my knowledge, that considers the possibility that childhood stress is linked to social status. When interpreting LEH results, the paper addresses that many osteoarchaeologists assign weaning related significance to peak LEH records while other studies show that this link is weak or non-existent. With the literature providing no definitive interpretation, researchers opt to attribute differences in LEH formation ages to “non-specific physiological disruptions specific to social status” (Miszkiewicz en et al 2012). The study does not include the skeletal remains of sub-adult and juveniles, which could’ve offered a more holistic picture. The paper concludes that the etiology of LEH and definition of stress are influenced by many factors, but ultimately wrap up by emphasizing that a high frequency and severity of LEH would still reflect a

continuum of stressful events in a child's life (Miszkiewicz 2012). This is a refreshing perspective as the writers do not ignore the multi-faced nature of LEH, but instead, emphasize how it can still be meaningful regardless.

Another study was conducted in the small market town of Lincolnshire, England. Cribra Orbitalia, vertebral neural canal (VNC) size, craniofacial fluctuating asymmetry and femoral length were recorded in 267 adults from an earlier agricultural community (n = 157)(AD 1150-1700) and a later urbanized, middle-class community (n=110)(AD 1700-1855) buried at St. Peter's Church, Barton-upon-Humber (Watts 2013). This provides a unique opportunity to discover how the transformation from agricultural society to an urban middle class society affected childhood development and adult longevity in this sample. Barton-upon-Humber is located on the Southern bank of the river Humber in Northern England, as referred to by the figure below.

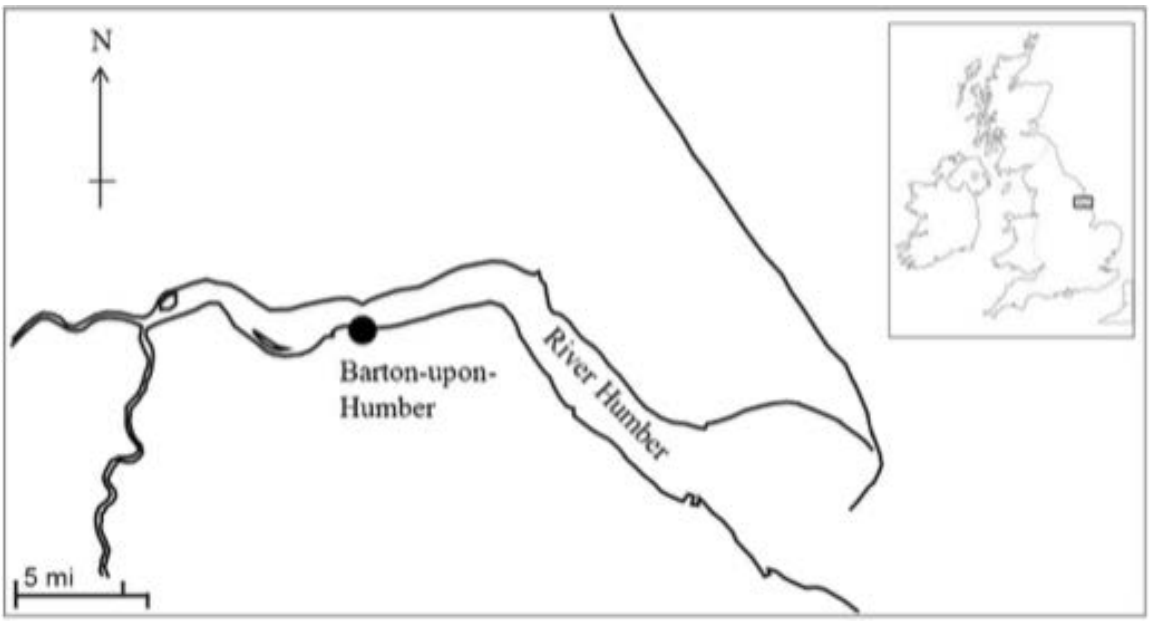

Figure 6

Figure 6 – Watts 2013 pg. 97

Barton's growth was limited by poor land access and by increasing urbanization and development of other port towns in the region during the early 14th century. Conditions remained relatively stable for most of its history, maintaining a population of around 1000 individuals. By the 15th century Barton-upon-Humber was described as a "poor rural town" (Clapson, 2005:17) and children were active members of the workforce and began receiving wages at the age of ten (Watts 2013). Significant changes occurred in the late 17th century when factories were being built. By the 19th century, the population had risen to nearly 4000 individuals, prompting problems with overcrowding, waste disposal, and contributed to the risk of contracting infectious and gastrointestinal diseases (Watts 2013). A total of 2750 skeletons were dated to clearly defined periods of cemetery use, and the individuals from St. Peter's Church are considered to represent a genetically homogenous population. Thus, results obtained are likely to reflect change in environmental conditions and not variations in genotype frequencies (Watts 2013).

The sample was split into two groups: Group 1 (n = 157) and excavated from cemeteries used between AD 1150-1700, & Group 2 (n = 110) were excavated from cemeteries in use between AD 1700-1855. Cribra Orbitalia frequencies and LEH frequencies are displayed.

Cribra orbitalia frequency.

Age-at-death	Group 1		Group 2	
	N[a]	%	N[a]	%
Young adults	22/54	40.74*	10/39	25.64
Mature adults	9/55	16.36*	8/56	14.29
Total	31/109	28.44	18/95	18.95

N[a]: affected individuals/observed individuals.
* Significant for age-at-death.

Linear enamel hypoplasia frequency.

Age-at-death	Group 1		Group 2	
	N[a]	%	N[a]	%
Young adults	34/59	57.63	30/52	57.69
Mature adults	16/36	44.44	15/32	46.88
Total	50/95	52.63	45/84	53.57

N[a]: affected individuals/observed individuals.

Figure 7

Figure 7 – Watts 2013 pg. 98

LEH data also demonstrates similar frequencies between groups, with 50 individuals (53%) in Group 1 and 45 individuals in Group 2 (54%). This indicates that just over half of the individuals from both periods who survived into adulthood experienced health insults which disrupted amelogenesis between one and six years of age (Watts 2013). Surprisingly, despite the transition from rural to an urban middle-class living environment, prevalence of stress indicators after AD 1700 did not change significantly between cemetery periods. This is high in comparison to rural medieval population of Wharram Percy, where 32% of adults displayed LEH (Mays 2007). These high levels may be attributed to an increase of levels of pollution and hygiene in a small town vs. a rural village. Regardless of improvements in housing and economic status, such improvements were not enough to protect individuals from non-specific stressors, including fevers, infections, and nutritional stress (Watts 2013).

Cribra Orbitalia was observed in 31 individuals (28%) from Group 1, and 18 individuals (19%) from Group 2. These prevalence rates are lower than in urban populations from medieval York, where 66% of adult individuals from low status population and 37% of individuals with higher status displayed orbital lesions.[12] It is hypothesized that these high rates can be attributed to overcrowding and poor sanitation. Skeletal remains from Christ Church Spitalfields in London (AD 1700-1850) showed that 34% of the total sample displayed Cribra Orbitalia.[13] For this sample,

[12] Grauer, A.L., 1993. Patterns of anemia and infection from medieval York, England.; Sullivan, A., 2005. Prevalence and etiology of acquired anemia in medieval York, England.

[13] Molleson, T., Cox, M., 1993. The Spitalfields Project. Volume 2.; The Middling Sort. Cox, M., 1996. Life and Death in Spitalfields, 1700–1850.

Cribra Orbitalia is hypothesized results from the use of fashionable infant feeding practices, which caused malnutrition and gastrointestinal diseases.

This is the only paper so far that has points distinctly to gastrointestinal disease, as opposed to multiple causative agents, and the severe nutrient losses associated with these may have been a factor in the development of cribra orbitalia in children under four years of age in both cemetery periods at St. Peter's Church. One fascinating claim is that age-at-death individuals who experienced health insults that caused cribra orbitalia no longer experienced a reduced adult lifespan. The explanation given here is that the changing environment and economic conditions seemed to have benefited the population in the long term. This is the first study to show a positive affect as a result of societal movement towards a more sedentary, yet secure and advanced lifestyle. However, it is unclear whether these lesions have the ability to remodel completely by adulthood. Some studies contradict this notion as higher rates of healed orbital lesions were observed in mature adults, illustrating that cribra orbitalia lesions can be retained well into adulthood.[14] Until more information is known about the remodeling abilities of such lesions, it is important to approach these findings with caution.

The paper is inherently similar to Taiwan and Northeast China studies as it examines a transition from hunter-gatherer to a more technologically advanced, yet sedentary lifestyle. The results seem to follow the same pattern, as improvements in economics and food reliability were not strong enough buffers to counteract stress. This paper really dives into the history of the location as they have information spanning

[14] Walker, P.L., 1986. Porotic hyperostosis in a marine-dependent Californian Indian population.; Grauer, 1993.

centuries for this region. This allows for in depth analysis of urbanization and how society's improvements affected general health. It's worth noting that children during this time were active members of the workforce. This could significantly impact childhood stress, whereas the previous studies have not provided insight as to what the children were actually doing during that time. Similar to the Haotaomuga paper, individuals were required at least three permanent anterior teeth to be included in the data set for LEH.

The last region of examination is West Virginia, America. In this study, linear enamel hypoplasia (LEH), tests the hypothesis that early life stressors contribute to decreased adult longevity in a human skeletal sample from the Late Fort Ancient site of Neale's Landing, West Virginia. Neale's Landing represents an extremely stressed population indicative of prehistoric agricultural societies. Researchers claim the most likely cause for stress at Neale's Landing is seasonal resource scarcity exacerbated by the ongoing Little Ice Age. Unlike other contemporary year round settlements in the area, Neale's landing never exceeded two acres and contained only a few families with a population at maximum of 40-50 individuals. It is important to note that there were preservation issues due to human modification of the land, bank erosion, agriculture, and bioturbation (root growth and woodchuck burrows), which contributed to this small sample size (Hemmings, 1977). Radiocarbon dating suggests initial occupation between A.D 1500 & 1550 and trade goods indicate occupation lasted until early 17th century. Evidence also shows that the population was preoccupied warfare and hunting relative to farming. Maize agriculture was prominent along with the hunting and gathering of local species such as nuts, large and small mammals, birds, and aquatic resources. This

region allows the researcher the ability to analyze “the effect of stress on Native American populations present in the Ohio Valley just prior to European contact.” (Wolfe 2014)

Researchers uncovered 34 human burials in 27 graves at Neale’s Landing. The assumption is that there are three extended families within the site that persisted for about a century. This study examined 7 sub adults and 11 adults. Four of the adults are male, three are female, and four are of indeterminate sex. Researchers looked at all teeth for each individual and simply marked if the signs of linear enamel hypoplasia were present or not. If an LEH existed, we measured the position of each defect from the cement-enamel junction (CEJ) using digital sliding calipers accurate within 1/100 of a millimeter to assess chronological age at insult. Two other sites are from Illinois (A.D. 1000 – 1350) and Ohio (A.D. 800-1100) is included to provide material to contextualize the stress experienced at Neale’s Landing (Wolfe 2014).

Thirteen individuals (72%) in this study show signs of linear enamel hypoplasia. This includes four adult males, two adult females, five juveniles, and three adults of indeterminate sex. These individuals are as young as five and perhaps as old as 50 years of age. Based on the average age of the sample, individuals with linear enamel hypoplasia (n=13) died on average at the age of 24.23 and individuals without linear enamel hypoplasia (n=5) died on average at the age of 25.10. The data are not significant at the $\alpha=0.05$ level ($p=0.905$)(Wolfe 2014).

The paper does an impressive job of utilizing the right variance tests to still gather meaningful information from the data and observe differences between each subsistence group. The comparison of many locations did show a significantly lower

mean age at death for individuals with enamel defects compared to individuals with normal teeth, at least supporting the notion of LEH being related to mortality. The comparison of this sample to other nearby samples once again reaffirms the representativeness of skeletal remains of the population. If post-contact remains could be recovered, this would be a great paper to study the affects of European contact. This paper is very thorough in terms of methodology, but the focus of the paper is narrow and not all possible factors are included. There could be legitimate reasons as to why the researchers don't explore other avenues, but such explanations are not offered when they should be.

This paper has a small sample size so the results may not be representative of the population at the time. The sample is also a relatively young population and cannot represent the full life span of the group. Researchers also state "the fragmentary nature of the sample prevents complete accuracy when ageing these specimens." (Wolfe 2014) Regardless of the downfalls of this sample, the data set from Neale's Landing is compared with several other sites from various geographic locations. The biggest fault in this analysis is revealed by the writer himself when he states, "Although compelling, the significant difference present masks the fact that the comparative sample includes samples from numerous populations that vary in subsistence practice, settlement structure, settlement size, among other variables". (Wolfe 2014)

Implications & Conclusions

Although there are a plethora of previous studies analyzing enamel hypoplasia and the relationship between decreased mortality, to date, no study compares these results cross-culturally. But there are studies that do have some plausible theories to consider. Steckel and Rose (2002) created a skeletal health index indicating that general health declines throughout human history as society transitions from simple to complex and hierarchical. This indicates that people who lived in large settlements were generally less healthy than hunter-gatherers. This paints a stark picture chronic disease replaces infectious disease and nutritional deficiency as the prominent driver of morbidity and mortality due to the modern developing world. However, LEH is present in a modernized society as evidenced by the samples of Lisbon, Portugal and Cleveland, United States, thus giving a broad factor of comparison across time periods (Wolfe 2014). Another theory called the osteological paradox questions the true implications of LEH. This suggests that those who survived long after the episode were the healthiest while those individuals without lesions may have died before the chance to manifest themselves. This questions if the presence of LEH really equates to less healthy. There is also the factor of sample size to consider. How can one decipher how many skeletal samples are really needed in order to consider the collection representative of the region. And if they are a reliable sample, how large of a region can they truly compare to?

One common problem became clear the more I sifted through the literature. There is a lack of standardized methods when analyzing for specific markers of stress. This makes it extremely difficult to compare data sets to one another and broaden the

context with which we are viewing the results. Some papers reference their methods from previous studies, which is a step in the right direction, but there is not one accepted practice. It doesn't have to be the most flawless methods, but a foundation of similarities must be present to be able to provide a global context. For the same certain fields of research the "scientific method", which essentially lays out the minimum standards for gathering proper evidence, paleopathology needs a method of its own. Only when this is accomplished, can we accept comparative results without doubt.

It is also important to recognize that markers of stress in bones and teeth imply poor health. Stress is not an objective reaction for everyone, there are more factors involved. There are lots of research about *protective factors* (e.g., warm, nurturing parenting; wealth), *homeostatic mechanisms* (e.g., metabolic adjustment to caloric deprivation during the prenatal period), and *cultural factors* (e.g., *familism* among Latino/a people appears to buffer against the effects of stress). The primary hormonal mediators of the stress response are glucocorticoids and catecholamines, which are essential for adaptation and maintenance of homeostasis and survival. Over time, they contribute to an allostatic load, which can accelerate disease processes. This load centers on the brain as the interpreter and responder to environmental challenges. Early childhood experiences of abuse and neglect increase allostatic load later in life that can lead individuals into social isolation, hostility, depression, and even conditions as serious as extreme obesity and CVD (Mcewen et al., 2000). Animal models support this claim of lifelong influences of early experience on stress hormone reactivity. Although the psychological factors of these ancient populations cannot be obtained, it is important

to keep this variable in mind as it may play a critical role in understanding results now and in future studies.

After all cases taken into consideration, Steckel & Rose's theory seems to be the most plausible explanation for any paleopathologic study that analyzes the same population over time, or two neighboring societies with different lifestyles. Some studies in this review reflect the presence of this paradox, such as in Lovell's paper. In the Indus Valley paper, a conclusion was reached that pathogen load increases with "sendentism and with denser populations because these facilitate both the exchange of infectious agents between people in close contact and the accumulation of human wastes and other refuse in and around the settlement" (Lovell 2014). Lincolnshire, England and Northeast China also reflected a decline in health when moving towards a more sedentary lifestyle. This provides insight into today's society as we are more sedentary than possibly ever before in history. We have outlived diseases and bred new ones as well, and there is valuable knowledge in paleopathology that can help combat our ever-changing biosphere.

Paleopathology can be referred to as a gateway study in the sense that professionals from multiple fields of science can look at the results and add a piece to the puzzle. In Rapa Nui, anthropologists and historians remedy the archaeological record and redeem the locals by erasing a history of cannibalism & warfare. Hawaii further emphasizes the impact of infectious diseases, providing valuable knowledge to etiologists and pathologists who aim to understand, create, and implement medical treatments based the historical and medical profile of each disease. The Mariana Islands challenges environmentalists to truly observe the impact of climate on the health of a

population. The Barbados slave population can be utilized as a basis of comparison for other slave populations globally as well as the represent the less healthy end of the spectrum. Anthropologists could be the most helpful in this case as the weaning practices seem to be the main factor and such practices are tied to culture. Lovell's study in the Indus Valley adds to the medical history of Malaria and explores all possible avenues, allowing researchers to easily add to the proposed theories through their own work. The cases in England may perhaps be of most interest to psychologists as the affect of SES on childhood stress is a thriving area of research. West Virginia as a stand alone case would improve if all other possibilities were thoroughly investigated, a task that could be accomplished via a diverse team of scientists. The applicability of paleopathology spans to modern times, as these same stress indicators will continue to appear on skeletal remains. Ultimately these studies reveal that bone lesions are still relevant to the study of health today and in the past. With the help of biologists, epidemiologists, archaeologists, anthropologists, and environmental scientists, the combined data could eventually lead to mitigation and aid in areas where medical technology and socioeconomic status may not be able to buffer the effects. With this perspective in mind, future studies should illuminate the unreliable shortcomings present, and further contextualize and interpret the association between development, nutritional, and environmental stress, in whatever form they may present themselves.

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