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Health Impacts at the Advent of Agriculture

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HEALTH IMPACTS AT THE ADVENT OF AGRICULTURE

by

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<u>Abstract</u>

The transition from a hunting and gathering lifestyle to one based in agriculture may have been the most crucial development made by past peoples, transforming not only diet, but social structure, mobility, and resource use. I present human skeletal evidence illustrating the consequences of agriculture on human health using case studies from prehistoric Mesoamerica, the American southwest, and regions in Asia. Such evidence has indicated that intensification of maize agriculture in the New World correlates with increased infant mortality rate, dental caries, iron-deficiency anemia, and an overall decline in general health while these health problems have little to no correlation to early intensification of rice agriculture in Asia. This is likely due to the decreased cariogenic nature of rice and its greater nutritional value compared to maize. Other possible causes include processing differences and greater dietary variety in Asia.

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HEALTH IMPACTS AT THE ADVENT OF AGRICULTURE

<u>Introduction</u>

The advent of complex agriculture brought about many changes for humans, including social stratification, sedentary settlements, and an increasing dependence on carbohydrate staples. Bioarchaeological research over the past 40 years indicates that, while complex agriculture may have revolutionized society as we know it, the continuous dependence on carbohydrate-based staples led to a variety of health problems. This has been well documented in the New World, where the transition to maize agriculture is marked by a general decline in health (Sobolik 2002:125-126). Diamond (1987:91) declared agriculture to be "the worst mistake in the history of the human race," noting how farming societies have experienced increased frequencies of disease, health problems, and social inequalities as compared to early hunter-gatherer societies.

However, the remarkable decline in health observed in the New World has not been as widely studied in other areas of the world. Assuming that dietary dependence on cereal crops leads to relatively similar negative health impacts, other forms of complex agriculture, such as rice cultivation in Asia, may have resulted in problems for the people living during these transitions. Did the introduction of agriculture in other areas of the world cause the same human health impacts observed in the New World? I predict that, while agriculture in Asia may not have impacted the health of new farmers as much as agriculture in the New World did, pathological bone markers that indicate a decline in health will increase in frequency after the transition to farming.

This research summarizes data from human skeletal pathological analyses used to

determine past people's health in three large areas: Mesoamerica, the American southwest, and regions in Asia. These pathological markers are the focus of case study analyses of human health in Mesoamerica and the southwest that build the general agro-health model as applied to the New World. This model is then compared to case studies of bone markers found in Asia to test if the advent of complex rice agriculture exhibits similar health impacts seen in the New World.

Origins and Impacts of Agriculture

Agriculture was a turning point in not only human health, but also social, technological, and economic development (Diamond 2002). Attempting to locate this key event in history is philosophical in nature, asking the question: at what point does simple environmental management become agriculture? Additionally, this process occurred at different places and times throughout history, making it difficult to pinpoint (Winterhalder & Kennett 2006:3).

It is generally agreed that domestication was likely not intentional at its very origins. Anthropologists do consider the incidental planting of wild plant resources as a domestic or agricultural action. The intent to plant and/or modify a plant is thought to be the distinguishing characteristic of domestication, though this is still a gray area (Hayden 1995: 274-275.) Using ecological knowledge, early hunter and gatherer societies may not have extensively harnessed their environment's resources like later farmers would, but they could have tended to wild species (Winterhalder & Kennett 2006:4). It is likely that early economies were mixed, with foraging and low-level cultivation combined. Smith (2001) notes that a period of about 6,000 years occurred between signs of initial

domestication of squash, beans, and maize in Mexico, and the first signs of farming-based economies in the area. Furthermore, these crops all were domesticated and geographically migrated at differing times and rates (Smith 2001:1326). Thus, it is difficult to place a defined boundary between these subsistence strategies, and the "transition" to domestication and agriculture is usually thought of as a long adaptive process rather than a specific point in time.

Nevertheless, the process of transitioning to agriculture can be observed in the study of ancient botanical remains from archaeological sites. Domesticated varieties of plants are often larger, more productive, and easier to harvest than their wild counterparts, and the continued selection of these appealing traits over others transformed wild plants into domesticated varieties (Winterhalder & Kennett 2006:3). These changes can include larger seeds, thinner seed coats, non-shattering seeds, and faster growth (Diamond 2002:701). Due to these changes, some domesticated plant varieties may have difficulty surviving in nature, and require human management (Winterhalder & Kennett 2006:3). Evidence of drastic plant morphological changes exhibited on remains obtained from archaeological records can signal shifts in subsistence patterns, from gathering from the environment to managing it, as increased controlled breeding produced plants more prosperous for human consumption (Eubanks 2001:494).

There are a multitude of reasons why early people may have made this transition from foraging to agriculture. One theory is that demographic pressure of a growing population would have forced hunter-gatherers to adopt agriculture (Winterhalder & Kennett 2006:5). This argues that hunter-gatherers reached an ""environmental carrying capacity" that resulted in the manipulation of plants and animals to avoid a food shortage.

While not completely discounted, a counter-response to this theory, using interpretations from the archaeological record, is that hunter-gatherer populations do not appear to be large previous to the agricultural transition and that large growths in population did not often occur until after this transition (Winterhalder & Kennett 2006:5).

Another popular theory seeking to explain the transition to agriculture is that environmental change incited the transition. Childe (1928) suggested that the onset of dry, arid conditions occurring at the end of the Pleistocene age caused a drought in the Middle East, ultimately pushing humans and animals together in river valleys and oases. This forced proximity could have been the first step towards domestication, initially with animals and then eventually with plants.

Continued research on Childe's theory showed that climate change at the end of the Pleistocene would have caused high latitudes to become warmer, with higher sea levels and rebounding forests. It is thought that areas would have been affected differently, with some experiencing mass extinctions of mega-fauna, and others experiencing a greater diversity and abundance of plant species. Adaptations to these changing conditions could have led to transitions in subsistence patterns, and ultimately to plant and animal domestication (Winterhalder & Kennett 2006:6).

Since agriculture was a process that occurred in various geographical and temporal locations, it is possible that differential pressures influenced different societies to transition to farming. Regardless of how the transition to agriculture was brought about, controlled management of food sources would have provided more stability and safety in times of need, and selective breeding of wild plants would make them easier for humans to harvest. Perpetual management of crops combined with a greater security in food

sources allowed previously nomadic societies to settle in sedentary villages (Hayden 1995: 278-279). These benefits of an agriculturally-based economy would have made it seem much more productive and efficient than a foraging-based economy, though it is questionable whether or not early agriculturalists would have recognized this (Diamond 1987:91). It is important to note that the domestication of animals, or pastoralism, was integrated with the domestication of plants, and may have occurred before plant domestication in some areas.

Reorganization in social structure and economy, including social stratification, frequently accompanies increased agricultural activity, which is likely the result of specialized labor in a productive community (Diamond 2002:703). This may also be due to the introduction of surplus resources, which would have been unwieldy in previously mobile, hunting and gathering societies (Diamond 2002:703). In an agricultural community, some individuals would possess more resources than others, or have a lesser/greater role in food production, creating a stratification of "classes" (Hayden:1995:277-279).

The first archaeological evidence of domestication has been noted in Mesopotamia, aptly referred to as the "fertile crescent." Since this occurs after the last climatic cooling period, many archaeologists suggest that a warmer, moister climate led to greater plant productivity necessary for agricultural success (Miller 1992). Evidence of agricultural intensification can be direct, such as that from botanical remains and remaining farming structures, or indirect, in the case of recovered tools and depictions in art (Miller 1992:43). Around 9,000 B.C., paleobotanical remains of morphologically transformed plants (barley, wheat, etc.) appear in the archaeological record (Miller

1992:42). During this time, sedentary or semi-sedentary settlements begin to appear as well. Size estimations of later sites based on structure size, frequencies of imported goods, and number of rooms suggest that some sites were hierarchically elevated in comparison to other sites (Bar-Yosef & Meadow 1995:74-78). Other signs of increasingly complex social organization and hierarchy can be seen in public facilities and burial styles (Bar-Yoself & Meadow 1995:78).

Soon after agriculture developed in Mesopotamia, archaeological evidence of agricultural development began to appear in other areas of the world as well, including India, Asia, and the New World. This is not necessarily due to the spread of farming techniques, but rather isolated, simultaneous development. While the health and social impacts of agricultural intensification haven't been as widely observed in all of these areas, much research has been done in Central America, where teosinte, the predecessor of maize (*Zea mays*), evolved into a staple crop due to direct human activity.

Human Skeletal Data

Health changes as a result of agriculture are best observed through the study and analysis of human skeletal remains, referred to as bioarchaeology and paleopathology. If present, and well-preserved, bones can yield a multitude of clues about a person's health prior to death. Bones not only tell a person's age or gender, but also indicate what they may have eaten, if they had children (in the case of women), what their occupation was, if they underwent body modification, were mobile while living, suffered injuries, or experienced any deficiencies or diseases. There are visible bone markers known to be caused by particular conditions, including anemia, scurvy, rickets, and osteoporosis

(Larsen 2002).Furthermore, isotopic ratios of nitrogen and carbon retrieved from bone can signal changes in diet in a population over time (Larsen 2002:120-121).

The skeletal system constantly grows and regenerates during a person's lifetime and responds to trauma in different ways. Nutrient deficiencies, disease, or overuse can damage bones due to a change or interruption in regular bone growth. Thus, an individual's skeleton at the time of their death can be thought of as a "history" of that person's life and can provide both direct and indirect information about their biological experience (White & Folkens 2002:2).

If an individual survives trauma or stress that inflicted damage to that skeletal system, bone cells begin the remodeling process and create new cells. This is how broken bones heal over time, and archaeologists can often tell when such an event occurred by marks of remodeling on the bones in question (Sauer 1998:330). If an injury to the skeletal system appears to have undergone bone remodeling, then the injury did not directly cause the person's death, and may have even healed before death. Conversely, if there are no signs of the remodeling process around bone damage of skeletal samples, then it is possible that the damage may be related to the cause of death, since no healing appeared to have taken place.

Osteological Pathology

There are numerous conditions that can be identified by bone markers. Perhaps the most frequently noted by archeologists are **dental caries** (Figure 1), commonly known as cavities. These appear as pits or "chalky" areas on the surface of teeth and are the result of the demineralization of the tooth, usually by bacteria (White & Folkens

2005:329). They are found all over the world and throughout time. Dental caries often correlate with the consumption of sugary or high-carbohydrate foods that are difficult to remove from the teeth. Archaeologists have used changes in prehistoric dental caries frequencies to observe subsistence shifts to agriculture, as well as to note any differences between gender, which may be the result of differing subsistence roles (White & Folkens 2005:329). While often small and easily treatable with modern technology, dental caries can lead to larger infections and eventually death if unattended to (Sutton et al. 2010:42-43).

Figure 1 - Dental carie (Larsen 2002).

Though not as potentially serious as dental caries, **dental hypoplasia** (Figure 2) is a condition of the teeth distinguishable by horizontal lines, grooves, and pits apparent on the surface of tooth enamel (Sutton et al. 2010:39). Dental hypoplasias, also called linear enamel hypoplasias, occur when the growth of enamel is disturbed by any metabolic stress experienced by the person. This stress could be dietary or pathogenic in nature, and should be analyzed in conjunction with other bone disturbances before conclusions on cause are drawn (Sutton et al. 2010:40). Dental hypoplasias have been observed in many

populations from around the world, and these populations are often characterized by elevated levels of malnutrition (Temple 2010:117). Some archaeologists use hypoplastic lines to estimate the age at which the person experienced stress, which can demonstrate aged-related patterns of diet and disease in a past society.
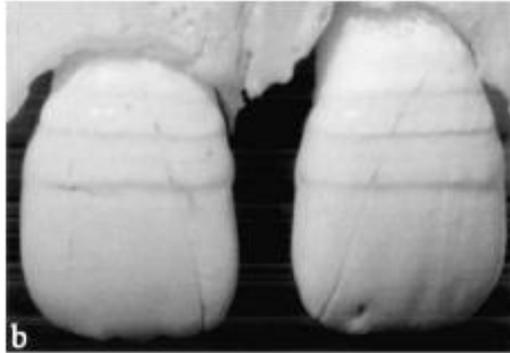
Figure 2 - Enamel hypoplasias (Larsen 2002).

While not pathogenic in nature, archaeologists may also note the wearing of teeth, which can indicate overuse, or a diet high in fiber or other abrasive material. However, the thinning of enamel, which is the protective layer of teeth, may cause an individual to become more susceptible to dental caries (Sutton et al. 2010:41-42). The level of tooth wear can sometimes provide an estimate of an individual's relative age, as older people often have much more tooth wear than younger people. Additionally, changes in tooth wear patterns over time may indicate a change in diet, or in food processing technology (Anderson 1965:496-497).
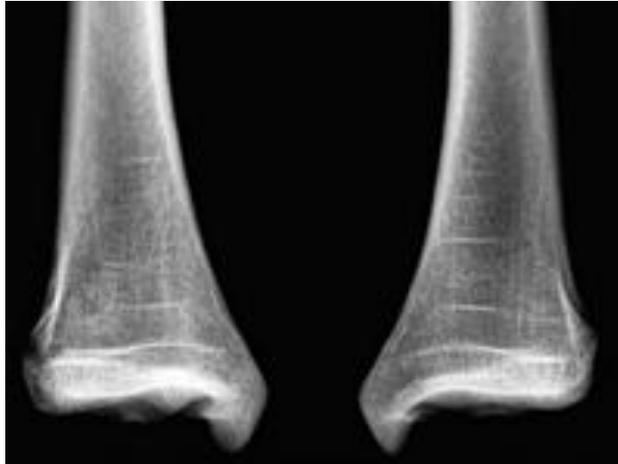
Figure 3 - Harris lines on the distal ends of two tibiae.
(http://radiographics.rsna.org).

Similar to the way stress can interrupt tooth enamel growth and cause dental

hypoplasias, stress can also interrupt an individual's normal growth and lead to the

formation of **Harris lines** (Figure 3), also called "growth arrest lines." These lines appear

horizontally on the long bones and are caused by a brief period of increased bone density.

Typically, the lines are located on the distal ends of the bones, since these areas grow

more rapidly relative to the rest of the bone. (Mays 1995:512). Because the ends of long

bones do not always preserve well in the archaeological record, Harris lines are not a

commonly studied bone marker. Furthermore, Harris lines are only visible by radiograph

or cross-section, possibly inhibiting archaeologists from including them in

bioarchaeological studies. Harris lines are similar to dental enamel hypoplasias because

the location of the lines on the long bones can indicate at which age the individual

experienced the stress that caused them (White & Folkens 2005:310)

Porotic hyperostosis (Figure 4), sometimes called spongy hyperostosis, is a

condition marked by lesions on the cranial vault (White & Folkens 2005:320). The

lesions are the result of the thinning of the outer bone surface and a widening of the

diploe, or spongy internal bone. This is a reaction to a lack of iron, or anemia. Many

archaeologists have debated the exact cause of iron deficiency leading to porotic

hyperostosis, since both poor, iron-lacking diets and pathogenic infection can cause

anemia. It has been noted in cases where both explanations are plausible (Boquet-Appel

2008: 285).

Cribra orbitalia (Figure 5) is the term used if porotic hyperostosis lesions occur

on the orbital roofs and is thought to be caused by the same conditions that result in

porotic hyperostosis. Often, but not always, the two conditions occur at once. Recent

research shows that cribra orbitalia may be more related to parasitic infection than

malnutrition (Temple 2010:118). It has also been suggested that direct trauma to the eye,

especially from infection, could inflict the lesions characteristic of cribra orbitalia

(Temple 2010:119).

Figure 4 - A case of porotic hyperostosis (Boquet-Appel 2008).

Figure 5 – A case of cribra orbitalia (Boquet-Appel 2008).

Osteoporosis is a condition that is common even in modern day. Osteoporosis occurs when bone is resorbed at an abnormal rate, causing low bone density at the ends of long bones, pelvic bones, between vertebrae, and/or at other joint locations (White & Folkens 2005:325-326). It can be caused by a number of factors, including a lack of dietary calcium and vitamin D, overuse of joints, and old age.

Osteological Population Studies

Aside from individual circumstances, the study of human bones can also aid population studies. Comparing age, height, and frequency of conditions of various skeletons from the same population can tell archaeologists about the general health of the group, or identify anomalous cases. If there are two or more distinct skeletal assemblages, then changes in these factors over time provide clues to transitions in diet, disease occurrence, or any other health changes (Larsen 2002:120).

The age of an individual can be estimated in multiple ways and will often be done

according to which skeletal remains are recovered. The most common method is by observing the individual's dentition, since the stage of tooth development can be compared with average tooth eruption patterns for children (White & Folkens 2005:365-366). Unfortunately, this method becomes less useful if the individual has reached adulthood and is no longer developing. Sometimes adult dental wear patterns can be compared to regular patterns of tooth wear in order to assign a relative age to an adult (White & Folkens 2005:369). Other ways to estimate age is by noting the fusion of cranial sutures or the pelvic bones. The stages of fusion for these bones have been determined for relative stages of adulthood, similar to those for dental development and attrition (White & Folkens 2005:369-380).

The stature of an individual is usually determined by long bone length, as limb length correlated with height at all ages. While this is not always a perfect correlation, formulas using femur and/or tibia lengths can provide a relatively accurate estimation (White & Folkens 2005:398-399). Changes in average stature of a population over time have been used in archaeological case studies as a proxy of nutritional changes (Sobolik 2002:137-138).

Agricultural Transitions in the New World

Mesoamerica was the cradle of maize domestication and intensification of agriculture in the New World. While the exact location of origin is still undetermined, it is commonly accepted by archaeologists and other scientists that maize was the result of selective breeding of the wild grass *teosinte* (Eubanks 2001:494). Teosinte is very unlike maize in form (Figure 6), bearing only five to seven hard seeds per flowering spike

(Eubanks 2001:494). Natural cross breeding with another wild grass (*Tripsacum*) for the selection of larger cob sizes, cob number, kernel row number, and easily harvested kernels caused the plant to evolve into a high-calorie, high-carbohydrate staple that could be grown easily and in large amounts (McClung de Tapia 1992:149,161). Higher yields of maize over time not only supported larger populations, but also allowed those populations to settle in permanent locations to grow maize, rather than roam the land for varied resources like earlier hunter-gathering societies (McClung de Tapia:161). Maize could also be stored for long periods of time, or processed into flour.
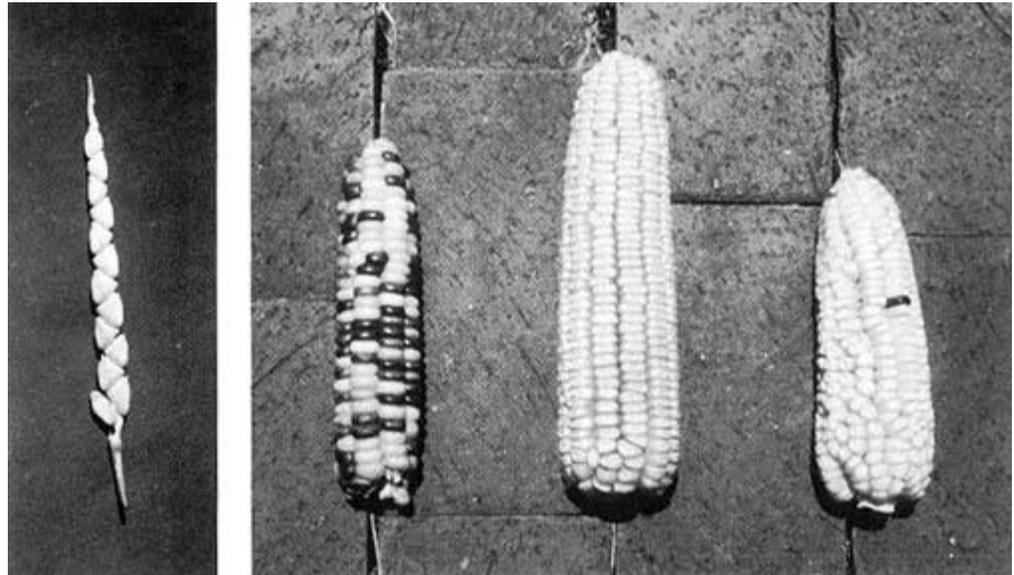
Figure 6 - Wild teosinte (left) compared to cobs of modern maize (right)
http://www.plantbiology.siu.edu/PLB304/Lecture26Poales/Poaceae.html

The first archaeological evidence of maize agriculture in Mesoamerica comes from the Tehuacan and Oaxaca valleys in Mexico (Pearsall 1995:163). The Coxcatlan Cave site in the Tehuacan Valley contains well-preserved remains of domesticated fruit-bearing trees dating to as early as 5500 B.P. Increases of seed size in several species,

including maize over time at this site, indicate specialized domestication (Pearsall 1996:174-175). After 4300 B.P., the use of maize increased, as observed in frequencies of phytolith and botanical remains, while other wild and domesticated plants decreased in the record. This correlates with evidence of settlement systems and sedentary villages (Pearsall:175). Other crops were domesticated and cultivated during this time, including beans, squash, pumpkins, and peppers (McClung de Tapia 1992:153-154). While these additional foods would add important variety to Mesoamerican diets, maize remained an important staple, and still is today.

Health Impacts of Agriculture in Mesoamerica

Anderson (1965) noted effects of agriculture on human health in this area when he found that skeletons uncovered from the Tehuacan Valley exhibited changes in dental wear and increasing frequencies of dental caries as agricultural intensification progressed in this region. Teeth of skeletons from the Ajalpan phase (1500 B.C. to 900 B.C.) showed less attrition than those of earlier periods (6800-5000 B.C.), and Anderson (1965:496) attributes this to the increasing consumption of softer carbohydrate as opposed to the much more fibrous diet of hunters and gatherers. Later phases (1900 B.C. to A.D. 1540) yield skeletons that show even less dental wear than previous phases, though dental caries are more prevalent (Anderson 1965:497). This would again correlate with an increasing dependence on softer carbohydrates and a decreasing consumption of wild, abrasive food sources.

Other signs of declining health observed on skeletons include cribra orbitalia and porotic hyperostosis, though there is debate about the relationship between these

conditions and agriculture (Temple 2010:118-119). With the increasing dependence on iron-poor foods such as maize in ancient Mesoamerica, it is possible that dietary anemia could cause these pathologies. However, these conditions could be caused by an increase in infection. This is plausible, because sedentary settlements in Mesoamerica would grow in size as maize agriculture intensified, presumably leading to unsanitary conditions, as well as larger host populations for pathogen transference.

Weaver (1981) examined infant and child remains from Casas Grandes, in Mexico during both the Viejo (A.D. 700 -1060) and Medio (A.D. 1060-1340) phases to determine whether increased cases of porotic hyperostosis support a hypothesized change in diet. Weaver notes several changes that appeared to happen between these periods, including a radical expansion of the Casas Grandes trade network and an increase in maize varieties during the Medio period (Weaver 1981:362). He also noted crowding and nucleated organization of settlement patterns during this phase that correlate with increased populations (Weaver 1981:362).

While there was no significant difference in frequencies of porotic hyperostosis between the two periods, there were more skeletal signs of infectious disease (post-cranial periosteal reactions) overall in the later period. The already high frequencies of periosteal lesions in both populations combined with increases in other signals of distress indicate that people (particularly children, in this case) were under great stress during this time, perhaps from dietary malnutrition. Changes in settlement patterns due to maize agriculture, however, appear to have worsened overall health and may be a result of higher occurrence of infections associated with sedentary living (Weaver 1981:363).

White and Wright (1996) compared percentages of porotic hyperostosis in both

adults and sub-adults from Mayan lowland sites during the end of the Classical period (~ A.D. 900). They found that populations had high frequencies of this condition, reaching 55-77% and 53-65% respectively (White & Wright 1996:159). Sub-adult frequencies were higher than those of later maize-growing societies, including Woodland (34%) and Mississippian (44%) in North America, but comparable to those of non-agricultural coastal Californians (51%) where porotic hyperostosis is linked to high rates of parasitic infection (White & Wright 1996:159). In Mayan adults, frequencies of porotic hyperostosis are higher than those in North America, but are comparable to maize-dependent southwestern pueblo adults (46-65%). While these data don't directly point out the causes of porotic hyperostosis, much lower frequencies in earlier Preclassic sites (12.5% of subadults and 3.6% of adults) indicates a decline in health over time.

Health Impacts of Agriculture in the American Southwest

Evidence of Intensification

The American southwest is a region that has gained much archaeological attention in regards to agricultural development. Due to a generally hot and arid climate, this area produces well-preserved remains of organic and inorganic material alike. Several lines of evidence exist that demonstrate an agricultural intensification of maize in this region following maize domestication in Mesoamerica.

Early botanical remains of maize from the American southwest were found in the Bat Cave site, which is located in western New Mexico, and were radiocarbon dated to 3740 ±70 years B.P. (Wills 1995:218). However, the emergence of maize in the southwest

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predates evidence of agricultural dependence by as many as 3,000 years; theories seeking to explain this delay include a gradually warming climate, as well as economic competition with other groups (Wills 1995:219). Before agricultural intensification, archaeological sites are comprised of either closed-site cave shelters or small structures that were likely inhabited seasonally.

Around 2,200 to 1,600 B.P., a substantial increase of open-air sites with evidence of maize cultivation appears. These sites have clear sub-surface storage constructions and increased burials, which implies population growth. There are numerous lines of evidence for agricultural intensification of maize in the Southwest during this time period. Hard et al. (1996) employed mano size and macrobotanical remains to trace this event.

Maize was ground with manos (hand-held stone pestles) and mutates (stone grinding slabs) to make the cereal grains into flour for easier digestion (Hard et al. 1996:256). While the general design of manos and metates are relatively the same throughout time, there appears to be a correlation between mano size and agricultural dependence (Hard et al. 1996:257-260). This is because a longer grinding surface can increase efficiency of grain processing, and has been documented in various ethnographic cases. In nearly all southwestern sites that produced remains of manos, the surface of the grinding stone increased through time in conjunction with other evidence of increasing maize dependence (Hard et al. 1996).

Hard et al. (1996) also studied macrobotanical remains from various southwestern sites, retrieving them either by flotation, or from recovered human coprolites. With these methods, the frequency of maize consumption can be estimated with recovered seeds from flotation, or directly observed in the case of coprolites. Botanical remains of maize

increase in frequency relative to earlier sites as early as 200 A.D., though some sites did

not experience this increased frequency until about 1200 A.D (Hard et al. 1996:274, 280).

These regional differences may be due to varying environmental conditions.

With these markers of agricultural intensification, it can expected that frequencies

of health conditions, such as dental caries, porotic hyperostosis, cribra orbitalia, dental

hypoplasia, and Harris lines, would increase in skeleton remains. Furthermore, if

agricultural intensification causes a decline in human health, there may also be a rise in

infant mortality rate, population growth, and changes in stature.

Bioarchaeological Evidence of Agricultural Intensification

In New Mexico, Buzon and Grauer (2002) conducted research on dental caries

and enamel hypoplasia frequencies to demonstrate that an increase in these ailments

correlates with agricultural intensification. The skeletal population they studied inhabited

the SU site in modern day New Mexico from A.D. 450 to 550 and exhibited high rates of

dental caries (Buzon & Grauer 2002). About 75% of recovered adults and sub-adults

exhibited dental caries on at least one molar and 26% of all recovered molars were

carious (Buzon & Grauer 2002:109). Antemortem tooth loss was evident in 63% of these

individuals, likely related to poor dental health and perhaps even a result of infected teeth.

Additionally, a very high frequency of dental hypoplasias was found at the SU site.

Ninety-one percent of all individuals with at least one canine tooth exhibited dental

hypoplasia, with 37 (69%) of 54 analyzed canines having the condition (Buzon & Grauer

2002:109). This frequency is similar to other sites known to have a high consumption of

maize, including Black Mesa at 90% and Carter Ranch Pueblo at 100% (Buzon & Grauer

2002:116).

Sobolik's (2002) study of the health of prehistoric sub-adults of the southwest included analyses of dental hypoplasia, Harris lines, porotic hyperostosis, cribra orbitalia, and changes in estimated stature. Since dental hypoplasia represents a temporary stunt in development, it is not a commonly observed marker of health. However, Sobolik's analysis of southwestern sub-adults (Sobolik 2002:143-144) indicates some very high percentages of dental hypoplasia (94% of permanent teeth from Hawikku [A.D. 1400 to 1680]) as well as some unexpectedly low percentages (7% of Arroyo Hondo Pueblo [A.D. 1300 to 1426]). This difference in rates of dental hypoplasia may be related to the time it takes for a development-ceasing stress to inflict observable signs on the skeleton. In the case of Arroyo Hondo Pueblo, which had a very high sub-adult mortality rate, some sub-adults may have died from the cause of the stress before the skeletal system could react.

Like dental hypoplasia, Harris lines are not extensively used in agricultural studies on health, and represent a temporary stress-inflicted stunt in development. In the Mesa Verde region, earlier populations (A.D. 600 – 975) actually have higher rates of Harris lines at 74% than do later populations (A.D. 975 – 1300) at 53% (Sobolik 2002:146-147). At the Dolores Project site (A.D. 600-1250) 46% of observed remains had Harris lines while at the Carter Ranch Pueblo site (A.D. 1100 – 1225) 80% had them (Sobolik 2002:146-147).

When the rates of porotic hyperostosis and cribra orbitalia of sub-adults from prehistoric southwestern sites were tallied, it was found that earlier, smaller sites actually had greater frequencies of the conditions (39%) than later sites (15%) (Sobolik 2002:141-143). This may be due to differences in identifying and recording the two conditions,

though variations in local resources may explain the observed difference.

Adult stature estimations for populations of various sites were made using long bone lengths. In some sites, such the Arroyo Hondo Pueblo site, earlier populations (A.D. 1300 to 1370) were estimated to be shorter (males: 163.9 cm, females: 156.2 cm) while later populations (A.D. 1370 to 1475) were estimated to be taller (males: 165.6, females: 153.5). In others, such as the Black Mesa site, earlier populations between A.D. 800 to 1050 were taller (males: 167 cm, females: 156.5 cm) than later populations (males: 163.1, females: 152.5) between A.D. 1050 to 1150 (Sobolik 2002:137-138). Thus, while changes in stature can sometimes indicate health changes in a population, no clear trend was observed in these data.

Porotic hyperostosis and cribra orbitalia have received much attention in studies of health in the agricultural Southwest for many years. In earlier works, El-Najjar (1975) inspected 539 crania from six skeletal assemblages of the Anasazis for signs of porotic hyperostosis and cribra orbitalia (the two were not separately distinguished in this research). Four of the series were from canyon bottom sites with high maize dependence, and the other two came from sage plain sites where diet was a mix of both animal and plant sources (El-Najjar 1975:920). Of all of these crania, 34.3% demonstrated porotic hyperostosis and/or cribra orbitalia. From the four canyon bottom dwelling sites, percentages of porotic hyperostosis and cribra orbitalia range from 49.3 – 71.8%, while percentages of the conditions from the sage plain sites ranged from 13 – 15.3% (El-Najjar 1975:922). El-Najjar attributed this to a lack of dietary anemia in maize-dependent settlements.

Boquet-Appel (2008) compiled skeletal data from 57 prehistoric southwestern and

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other North American burial sites to analyze frequencies of dental caries, porotic hyperostosis, and cribra orbitalia relative to the transition from a primarily foraging lifestyle to a primarily horticulture/farming lifestyle. The frequency of dental caries generally increased with time, with a significant rise after signs of a transition to an agricultural lifestyle, represented by *dt* (Figure 7; Boquet-Appel 2008:281).

The expression of the transition to agriculture as a point in time (*dt*) recalls Smith's (2001) observation that the transition from a foraging-based economy to a farming-based economy was actually a multi-millenia process in the Americas, beginning with the first signs of plant domestication. While the representation of this process as *dt* in Boquet-Appel's work (2008) may be based off of archaeological signs of a farming-based economy, it should be noted that this dismisses events leading up to this, including initial plant domestication or the spatial migration of domesticate species.

Converse to the results of Sobolik's (2002) study of southwestern sub-adults, Boquet-Appel's work (2008) demonstrated a trend of increased frequencies of porotic hyperostosis after transitions to farming and a similar trend for cribra orbitalia as well (Figures 8 and 9; Boquet-Appel 2008:282-283).

Potential issues with these data plots are the lack of data points previous to *dt*, and the scattering of points after *dt*. The first issue may only be resolved with data from more sites, as the results may be skewed with smaller sample sizes. The scattering of data points after *dt* suggests that, as more people in the past turned to agriculture, variability of health impacts over time increased. This variability could be a manifestation of differing social class, diet breadth, or genetics
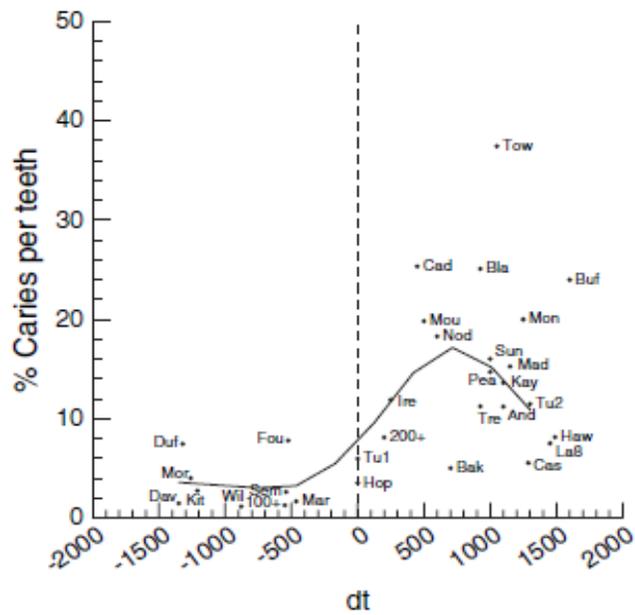
Figure 7 – Dental caries frequencies relative to
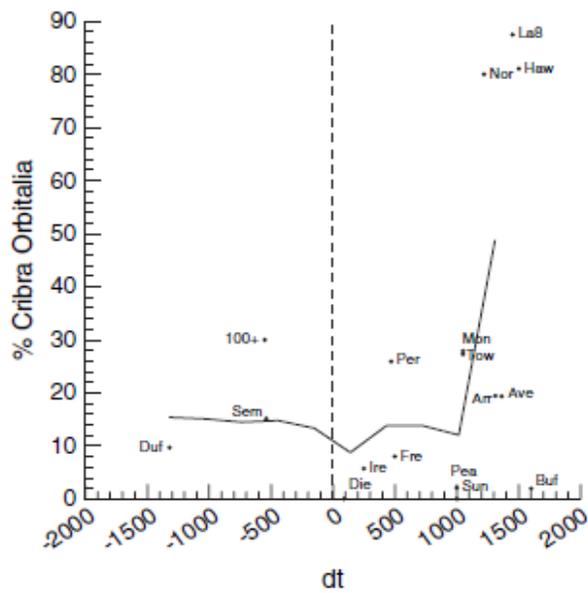the transition to agriculture (Boquet-Appel 2008).

Figure 8 – Cribra orbitalia frequencies relative to
the transition to agriculture (Boquet-Appel 2008).
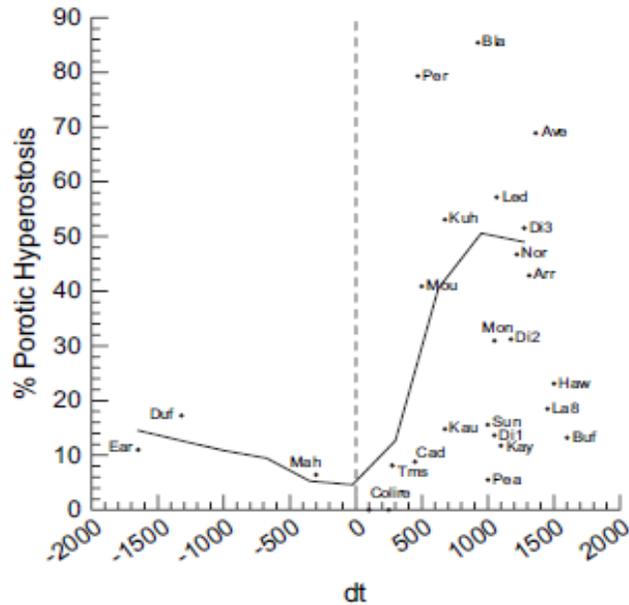
Figure 9 – Porotic hyperostosis frequencies relative
to the transition to agriculture (Boquet-Appel 2008).

While not all of these studies support the hypothesis that maize agriculture had a

definitively negative impact on overall health, many demonstrate that some populations

were strongly impacted, as shown by high rates of dental enamel hypoplasia and caries.

This variability may be due to some groups consuming more maize as primary food

sources while others complimented maize with other food sources. After all, other plants

were domesticated around the same time that maize was, including beans and squash.

While these case studies make little to no reference to faunal assemblages of the various

sites, animals such as hares or birds most likely contributed protein and other nutrients to

the diet of past people. Another explanation could be that nutritional differences arise

from the varying social statuses of sites. It is likely that some sites were larger, wealthier,

or more important than others, and this could influence the quantity or quality of food being received.

Additionally, some groups may have been more impacted by the indirect effects of sedentary agriculture, including parasitic and bacterial infections associated with waste accumulation. Clean water, especially in an already arid environment, could be scarce if being used to irrigate crops or if it was in close proximity to areas of waste. Higher populations would increase the contact rate of pathogens, allowing them to spread more quickly and infect more potential hosts. Studies on human coprolites for signs of possible pathogens could yield direct information about the disease load on past people.

Agricultural Transitions in Asia

The bioarchaeological evidence of a decline in health caused by agricultural intensification presented so far is only in the New World, and is only in regards to maize-concentrated agriculture. If the adoption of a carbohydrate-concentrated form of agriculture caused negative effects in these areas, it is possible that other carbohydrate focused agricultural developments, such as rice agriculture in Asia, could inflict similar consequences. Rice, like maize, is a grain that can be grown in large quantities relatively quickly. While nutritional studies show that rice is quite nutritious (Dodds 1960:318), it is not a complete protein and does not satisfy the full nutritional needs of a human being. Fewer studies have been conducted on the impacts of Asian rice agriculture than maize in the New World. Furthermore, these studies primarily focus on dental caries and tooth wear, leaving out data on porotic hyperostosis and other bone markers.

Southeastern Asia is a region that has experienced much climate variability in the

past 10,000 to 12,000 years, with warming and cooling periods that lasted about 500 to 1500 years (Higham 1995:127-129). Colder periods would have been accompanied by falling sea levels and decreased precipitation, while warmer periods were accompanied by rising sea levels and increased precipitation. Early sites that date to warmer periods in southern China (11,500 to 8,500 BP) produce evidence of wild rice consumption, and it is likely that warmer and wetter climates were favorable for rice growth (Higham 1995:133). Later sites in the Yangzi Valley during other warm periods (southern China, 7,000 – 5,900 BP) show an increase of rice remains, including grains, husks, stalks, and leaves (Higham 1995:137). Rice was accompanied by marine sources and other plant foods. The weight, size, and thickness of the rice grains show that rice had been domesticated and modified from its wild form.

The presence and frequencies of domesticated rice in later sites in Asia demonstrate an expansion of rice domestication from the Yangzi valley to southern regions of Asia guided by both rivers and the Pacific coast (Higham 1995:137). Significant dependence on domesticated rice reached others areas of Asia as well, becoming apparent in Korean and Japanese archaeological records around 3500 and 3000 years BP respectively (Crawford 1992:14).

Japan

Temple and Larsen (2007) studied dental caries frequency in remains of people from the Yayoi period in Japan (2500 BP to AD 300). These people were one of the first agricultural groups to exist in Japan, depending on domesticated wet rice as a dietary staple. Evidence of this activity is seen through well-preserved rice fields and isotopic

ratio analysis (Temple & Larsen 2007:505). Yayoi period sites in three areas: southern

Honshu (2500 – 1700 BP), northern Kyushu (2100 – 1900) BP, and Tanegashima Island

(2100 – 1700 BP), were used in the study. The frequencies of caries from these sites

were then compared to those of an earlier group of foragers in Japan during the Jomon

period (4000 – 2500 BP).

While there were no significant differences in dental caries and tooth attrition

prevalence between Jomon period foragers and Yayoi period people of Tanegashima

Island and northern Kyushu, there was a much greater frequency of carious teeth

observed among Yayoi period people of southern Honshu. This variation in carious tooth

frequencies may indicate varying diet. Additionally, women appeared to have a greater

frequency of carious teeth and tooth attrition than males in southern Honshu, yet both

genders had similar frequencies in northern Kyushu. This is likely due to dietary

differences in southern Honshu rather than biological differences (Temple & Larsen

2007:508).

A more recent study by Temple (2010) reexamines differences between western

Jomon foragers, eastern Jomon foragers, and Yayoi farmers by comparing frequencies of

cribra orbitalia and linear enamel hypoplasia from each group. Temple predicted that

these conditions will decrease in occurrence over time from foraging economies to

farming economies. This prediction is based on evidence that Jomon foragers,

particularly those from western Japan, had a nutritionally poor and narrow diet and that

wet rice agriculture provided a steady, stable diet that could compliment earlier food

sources (Temple 2010:113).

The Yayoi group had a lesser prevalence of anterior, permanent teeth exhibiting

linear enamel hypoplasia (30.3%) compared to both eastern and western Jomon foragers (36.8% and 56.7% respectively) (Temple 2010:116). The frequencies of adults from both Jomon foragers and Yayoi farmers with cribra orbitalia were comparable, at 8.6% and 8.8% respectively (Temple 2010:117). The frequencies of Jomon and Yayoi sub-adults with cribra orbitalia were higher than those of adults, but also nearly identical at 50% and 50.1% respectively.

Temple's (2010) hypotheses are supported by these numbers, which indicate that Yayoi farmers were in better health than Jomon farmers, due to an expanded and more stable diet. It also appears that western Jomon people were in poorer health than their eastern counterparts. Temple proposes that this is due to the higher consumption of terrestrial mammals by eastern people and a possible increase in population density on the west side of Japan (Temple 2010:117). The decrease in body size and age of deer and marine food sources of western Jomon foragers over time signals environmental resource depression, a common consequence of increased density of human populations (Temple 2010:117).

Lastly, Temple argues that the consistent frequencies of cribra orbitalia over time and dietary changes means that this condition is less related to diet than it may be to parasite infection. There are a number of known parasites that were possible causes of cribra orbitalia cases, and it would be difficult to distinguish these with the archaeological record alone (Temple 2010:118-119).

Thailand

Tayles et al. (2000) studied dental caries frequencies from three rice-dependent

populations from prehistoric Thailand. The earliest site, Khok Phanom Di, lies in the Gulf of Thailand and was a sedentary, but mostly hunter-gatherer settlement that dates to 2000 – 1500 BC. This site did yield domesticated rice that was likely transported from other areas, as well as 154 human skeletal samples (Tayles et al. 2000:70). The second site, Ban Lum Khoa, is located in northeastern Thailand and dates to 1400 – 500 BC. This site included domesticated rice remains, as well as aquatic and animal protein sources, and yielded 110 individuals (Tayles et al. 2000:71). The final and latest site, Noen U-Loke, is located only 20 km inland from Ban Lum Khoa and dates to 300 BC to AD 300. This site yielded 127 burials, many which were filled with domestic rice grains. The large quantities of these burial deposits, as well as those in other deposits and recovered farming tools (spades, sickles, and hoes), indicate increased agricultural productivity (Tayles et al. 2000:71).

Tayles et al. (2000) predicted that, like maize-dependent populations of the New World, prevalence of dental caries would increase over time. After the skeletons were grouped by age and sex, the molars, premolars, and canines were analyzed for caries. However, despite a greater dependence on rice agriculture over time, it was found that dental caries prevalence actually decreased over time, as well as gender variation in carious tooth prevalence. Tayles et al. (2000) suggests that sample size, dietary variation, and changes in rice processing may have affected these results, though it is possible that rice agriculture simply did not have negative impacts on dental health in this area.

Another paleopathological study in Thailand (Pietrusewsky and Douglas 2002) looked at one site, Ban Ciang, in northeast Thailand. This site has three primary sequences; an early period (2100 – 900 BC) that consisted of a hunter-gatherer-cultivator

economy, a middle period (900 – 300 B.C.) that experienced a low of woodland and gain of grassland, and a late period (300 B.C. - A.D. 200) that consisted of wet-rice agriculture. All three sequences yielded human skeletal remains that were analyzed and compared for cribra orbitalia, dental caries, enamel hypoplasia, and stature.

Like Tayles et al. (2000), Pietrusewsky and Douglas (2002) found that the number of carious teeth decreased from early to late burial groups at Ban Chiang (Pietrusewsky & Douglas 2002:166). This, they reported, may actually be an effect of a shift in agricultural focus from yam, which is sticky and starchy, to rice, which is less cariogenic. However, there was a statistically significant increase in the frequency of enamel hypoplasia on permanent adult teeth from the early to late periods, indicating increased stress from some sort of environmental pressure. Furthermore, the positioning of the lines on the surface of the teeth demonstrates that the stress causing the condition occurred earlier in the people's lives through time (Pietrusewsky & Douglas 2002:166).

Cribra orbitalia was not detected on male adults from the early group, but two of the four male individuals (50%) from the late group had the condition (Pietrusewsky & Douglas 2002:168). Females with the condition increased over time as well, with 2/9 individuals from the early period having the condition (22.2%) and 2/6 specimens (33.3%) from the late period having the condition (Pietrusewsky & Douglas 2002:168). However, the frequency of cribra orbitalia decreased in subadults at Ban Chiang, with 5/9 affected individuals from the early period (55.6%) decreasing to 1/6 affected individuals (16.7%) in the late period. Unfortunately, small sample sizes lessen the statistical accuracy of this data, and when all individuals are combined, there is a relatively insignificant change in cribra orbitalia frequency over time (Pietrusewsky & Douglas 2002:168).

When the estimated mean stature of early males and females was compared to that of later males and females, no significant difference was found. However, there was a slight increase of about 0.3 – 0.9 cm for both males and females over time, regardless of which method was used for estimating stature (Pietrusewsky & Douglas 2002:169).

Discussion

With the exception of an increase in dental enamel hypoplasias over time, Pietrusewsky and Douglas's study (2002) supports that overall health at the Ban Chiang site remained relatively steady, despite intensification of rice agriculture. Combined with the results of Tayles et al. (2000), Temple (2010) and Temple and Larsen (2007), it appears that rice agriculture did not have the same dramatic impact on health in Asia as maize agriculture did in the New World. In fact, Pietrusewsky and Douglas's data (2002) on enamel hypoplasias at Ban Chiang provide the only positive correlation found in the described studies that would support otherwise (Table 1). Temple's (2010) study even demonstrates that health may have improved with the beginning of wet rice agriculture in Japan, as farming provided a steady diet that earlier foragers lacked. With more archaeological research in Asia regarding ancient agriculture and larger samples sizes, the health impacts of rice agriculture, if any, can be more apparent.

Unlike the case studies in Asia, those focusing in the American southwest provided many positive correlations between agricultural intensification and declining health (Table 1). This includes increases in frequencies of porotic hyperostosis and cribra orbitalia (El-Najjar 1975; Boquet-Appel 2008), dental enamel hypoplasia (Buzon & Grauer 2002; Sobolik 2002), Harris lines (Sobolik 2002) and dental caries (Buzon &

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Grauer 2002; Boquet Appel 2008) throughout time. While some data conflict, there is clear evidence of a decline in overall health in the American southwest. As Larsen (1995:204) explains, "Biological changes did not occur uniformly within populations adopting agriculture. Rather, segments of past societies were affected differentially." Regional and cultural variation should be considered when analyzing large data sets such as those used in this paper. Status, diet breadth, environment, and genetics could all play a role in health differences noted between sites in the American southwest.

It is important to note that each bone marker and condition analyzed by these studies have their own causes and circumstances, dental caries being a dietary condition, whereas enamel hypoplasia, porotic hyperostosis, cribra orbitalia, and Harris lines can be caused by a multitude of stresses, dietary or otherwise. Thus, varying environmental pressures could produce varying frequencies of bone markers, depending on how populations were impacted. Further, the presence of high rates of enamel hypoplasia in Asia may be inflicted by non-dietary, secondary impacts of agriculture, perhaps an increase of pathogenic infection. The apparent differences in overall health impacts caused by agriculture in the New World and Asia could be due to a large number of factors, including the less cariogenic nature of rice, greater diet variation, or greater nutrition in rice as compared to maize.

In response to concerns about health impacts of carbohydrates on modern populations, some studies have been done to compare rice and corn, among other cereals. An experimental study (Dodds, 1960) compared frequencies of dental caries of rats that were fed four different processed and raw starchy cereals: oats, wheat, corn, and rice. These rats were fed a single cereal for 60 days, being weighed once a week, and then

analyzed for dental caries. It was found that, of all cereals, wheat was the most cariogenic, followed by corn, rice, and oats (Dodds 1960:318). Also, the raw, unprocessed rice had much more protein than raw corn, and resulted in a higher average daily growth (1.35 mg/day) than the corn diet (0.71 mg/day) (Dodds 1960:319). While special considerations, including the influence of grain processing and inter-species application, should be taken into account, the results of this study suggests that rice is a more healthful grain option than corn or wheat.

Tayles et al. (2000) noted similar observations as well, describing how studies of modern children demonstrate that rice is a less cariogenic cereal in comparison to others (Tayles et al. 2000:78). The physical properties of the grains, corn being "stickier" than rice, may play a role, since dental caries are caused by the bacterial consumption of residual food (Tayles et al. 2000:79). Furthermore, an increase of sugar in a diet, regardless of the consumed cereal, dramatically increased the frequency of dental caries, so perhaps additives, such as sugar, could cause an increase of dental caries in some past societies (Tayles et al. 2000:78).

Thus, an intensification of rice agriculture may not be visible in dental caries frequencies, but this does not mean that health changes did not take place in some areas. Larsen (1995:190) states that rice is still a protein-deficient food and also inhibits vitamin A activity. If there were indeed negative health impacts in areas where rice became a dominant staple, then this would be visible in other bone markers, perhaps porotic hyperostosis/cribra orbitalia or Harris lines. The study of dental enamel hypoplasia at Ban Chiang, and its increase of occurrence over time, supports this possibility that declining health can be seen in other ways.

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Temple's (2010) study may contradict this, as it was found that linear enamel hypoplasia frequencies decreased and cribra orbitalia frequencies stayed steady with the introduction of wet rice farming in Japan. However, health changes resulting from intensified agriculture may have affected areas differently. Temple (2010) explains that some groups in Asia ate more terrestrial mammals and others ate more marine food sources, which would account for health differences between early eastern and western Jomon foragers (Temple 2010:117). With the addition of domesticated rice in the Yayoi period, health generally improved due to a broadened diet, but perhaps there was likely still diet variation between groups due to prior dietary differences.

So far, most studies on agricultural intensification in Asia focus on dental caries, and this subsequently yields little information on general health. Perhaps an expansion in focus to include porotic hyperostosis and other markers would contribute a greater understanding of overall health, especially if more sites and areas were studied.

Nevertheless, the differences between health impacts of ancient maize and rice agriculture are becoming clearer. Rice appears to be healthier cereal staple than maize, both in nutrition and cariogenic nature. Furthermore, diets in coastal Asia may have been broader than those in the inland New World, which would have lessened the health effects of agricultural intensification.

	Maize agriculture (American Southwest)				Rice agriculture (Japan and Thailand)		
	Sobolik (2002)	Boquet-Appel (2008)	Buzon & Grauer (2002)	Temple & Larsen (2007)	Temple (2010)	Pietrusewsky & Douglas (2002)	Tayles et al. (2000)
Dental Caries	-	Dental caries increase over time.	Very high frequencies.	No significant changes.	-	Dental caries decrease over time.	Decreases over time.
Dental Enamel Hypoplasia	Low, but increases over time.	-	Very high frequencies.	-	Decreases over time	-	Increases over time.
Cribra Orbitalia	High frequencies.	Increases over time.	-	-	No significant changes.	-	No significant changes.
Porotic Hyperostosis	Very high frequencies.	Increases over time.	Low frequencies	-	-	-	-
Harris Lines	Very high frequencies.	-	-	-	-	-	-

Table 1 – A comparison of human health impacts noted by each case study.

It was not known exactly how maize and rice were processed at all of these sites, but the methods by which the cereals were prepared could also play a role in nutrition, as certain processes can enhance or decrease the bioavailability of vitamins and minerals. While grinding grains, such as with a mano and metate, the bioavailability of iron, zinc, and calcium can increase, but is countered by a loss of the content of these nutrients in the cereal (Hotz & Gibson:2007: 1097-1098). Soaking, on the other hand, can enhance the absorption of iron, zinc, calcium, while thermal processing (cooking, baking, etc.) can either inhibit or enhance absorption of nutrients depending on the plant species (Hotz & Gibson 2007:1097).

Due to the presence of manos and metates at many southwestern and Mesoamerican sites, it can be assumed that maize was ground, but further food processing is not mentioned. If so, it is possible that some nutrients were lost in this grinding process. Rice was, and still is, commonly prepared by boiling, which could increase the bioavailability of important nutrients. However, as with maize, the possibility of any further processing is unclear.

Conclusions

This thesis focused on health impacts of complex maize and rice agriculture in the New World and Asia as seen through human skeletal samples. In the New World, various archaeological case studies have supported that the advent of maize agriculture consequently caused health problems, including dental infections, dietary deficiencies, and possibly increases in pathogenic infections. The case studies employed bone markers, such as dental caries, porotic hyperostosis, cribra orbitalia, Harris lines, and dental

enamel hypoplasia, on human skeletal samples as evidence of these health problems.

Since Asia is another area in the world where a complex form of cereal agriculture became intensively developed, it was proposed that a similar decline in heath would be observed on past people's skeletons. The case studies from Asia did not support this, as dental caries appear to become less frequent through time, even with an intensification of rice agriculture, and no other bone markers of declining health are prominent. Many possible reasons behind this difference can be postulated, including the less cariogenic nature of rice, differences in dietary variation, greater nutrition, processing differences, and genetic variation. Additionally, it is possible that more archaeological research, particularly on bone markers not related to dental health, could yield further information on the health impacts of rice agriculture in Asia, if any.

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