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Diet, disease, and health in prehistory and history: The foraging to farming transition

Clark Spencer Larsen

Abstract

The transition from a lifeway based on production and consumption of wild plants and animals to domesticated plants and animals began some 10 to 12 thousand years ago, originating in a dozen or more independent centers and spreading around the globe. Today, nearly all humans are dependent on domesticated plants and animals for meeting all dietary and nutritional needs. A rapidly expanding bioarchaeological record based on analysis of stable isotope data for carbon and nitrogen and paleopathology from around the globe is providing new understanding of the impact of this transition on human health. Consumption of cereal grains meets energy requirements, but provides insufficient nutrition, resulting in decline in health and well-being. Specifically, bioarchaeological study from a range of settings around the world reveals a decline in oral health (dental caries, periodontal disease) and skeletal health (nonspecific and specific infectious disease). The former reflects the increased consumption of carbohydrates, associated changes in oral flora, and conditions conducive to poor oral health. The latter reflects increasing population size, aggregation, and sedentism, and circumstances that promote the maintenance and spread of pathogens. This period of time is important to study because it provides the context for who we are as a species today and looking for answers to questions about our future status, viability, and sustainability moving forward.

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Introduction

The success of humans today, numbering more than 7 billion at last count, is linked to sustainable food production, largely derived from production of domesticated plants and animals. These food sources provide the nutrition necessary for reproduction, growth and development, and health through the years of adulthood. Today, our species is completely dependent upon these plants and animals for its survival. This dependency has been so for only a tiny part of the history of humans. Humans and human-like ancestors have been around for some 6 to 7 million years, but humans first started consuming domesticated plants and animal just 10 to 12 thousand years ago. And, even then, the first record of domestication shows that the amount of domesticated vs. wild resources in daily diet was quite small and involved just a few places on the globe. But, domestication must have been of value for humans, if for no other reason that it fueled a remarkable economic and population growth such that virtually all humans living today are completely dependent on domesticated food sources, especially cereal crops. It is clear that without farming, the globe and the record of humanity that occupies it would be a very different place, at least certainly with a much lower world population size.

As it has been in the last several millennia, the growth of population and its sustainability in the 21st century is highly linked to food production, and especially to the so-called superfoods–maize, wheat, and rice. Anthropologists and other social and behavioral scientists are very curious about the foraging-to-farming transition, and issues relating generally to the transition from living on exclusively wild to exclusively domesticated plants and animals, the intensification of this major economic change once it was set into motion, and its outcomes. They ask the following fundamental questions: Why and when did the shift occur? How did it spread? What were the benefits and costs for those societies that adopted domesticated plants and animals? The first two questions are not easy ones to answer, but in general we know that plant domestication arose independently in at least a dozen primary centers throughout the world (and likely more), including in North America, South America, Asia, and Africa. Europe was not a primary center, but it rapidly adopted domesticated plants and animals as a central food source. The western Asian source of key domesticates – wheat, barley, and rye– first got to southern Europe and spread northward, reaching Scandinavia by six thousand years ago (various in Whittle and Bickle, 2014).

There has long been a debate about the vector for the spread of agriculture into Europe, earliest in southern Europe and latest in northern Europe reaching Denmark and Sweden relatively late. Did it arrive via immigrants from western Asia bringing with them the seeds of the idea, so to speak, or was it via cultural diffusion not involving actual people moving, just the ideas? The archaeological record based on the study of plants, material culture, and ancient DNA is beginning to show that the process involved migration by farmers and their replacement of local hunter-gatherers is highly unlikely. Rather, Europe in the Holocene during the transition from foraging to farming involved considerable movement of both ideas and people. In reality, then, the spread of agriculture throughout the continent was complex (Linderholm, 2011; Robb, 2014). And, that is similarly the case in other localities around the world.

This paper addresses the outcomes of the agricultural transition, and especially as these outcomes are based on the study of ancient human skeletal remains recovered from archaeological sites. The following discussion focuses primarily on the general patterns of diet, disease, and health for assessing quality of life generally. The discussion here employs the science of bioarchaeology–the study of human remains from archaeological settings–in order to identify answers to questions about costs and benefits of a lifeway based in part or in whole on production and consumption of domesticated food sources, especially plants. Human remains provide a fund of information about health, especially with respect to the impact of consumption of domesticated plants and a range of issues pertaining to diet, lifestyle, and changing living circumstances (Larsen, 2015). Domesticated plants are carbohydrates, and thus, they provide a central source of energy, but have nutritional deficiencies that serve to lessen the body's ability to be in a state of homeostasis and health. In addition, in comparison of forager and farmer lifestyle, there are general differences in social organization and settlement pattern whereby the living conditions associated with plant production are characterized as generally larger, more concentrated groups of people living in semipermanent to permanent settlements.

Thus, combining what we know about the biology of bones and teeth and how environmental factors affect these tissues in growth and development through the life course gives the study of bioarchaeology a central position in the ongoing dialog regarding the recent history of health, especially over the course of the last 10,000 or so years when farming is first introduced, spread globally, and intensified. If for no other reason, this period of time is important to study because it provides the context for who we are as a species today and looking for answers to questions about our future status, viability, and sustainability moving forward (Brooke and Larsen, 2014; Larsen, 2006; Steckel and Rose, 2002).

Documenting diet from the dead: The bioarchaeological record

The foods we eat have a considerable role to play in our health and wellbeing, largely because the foods we consume provide key nutrients necessary for maintenance of bodily functions, growth, development, and replacement of body tissues (including bone), and well-being overall. The application of geochemistry and stable isotope analysis, especially of stable isotope ratios of carbon (^{12}C, ^{13}C) and nitrogen (^{14}N, ^{15}N) have provided an explosive increase in our understanding of dietary and associated adaptive shifts since the method was first introduced by the collaboration of an archaeologist and a geochemist in the late 1970s (van der Merwe and Vogel, 1978; Vogel and van der Merwe, 1977). This event commenced a revolution in dietary reconstruction, opening up an understanding for the timing and spread of plant domestication throughout much of the world (Larsen, 2015). Unlike dietary reconstruction from plant and animal remains, stable isotope analysis provides documentation of the relative importance of specific foods and proportions consumed, thereby facilitating an understanding of nutrition (Katzenberg, 2008; Larsen, 2015; Schoeninger, 2010). Thus, in addition to providing a record of the timing and spread of plant domestication, stable isotope analysis also gives us a window onto the quality of the foods consumed.

Documentation of isotope signatures passed from the foods consumed to the tissues of the consumer via metabolism of foods consumed provides a remarkably robust record of food pathways. Among the best documented examples of the importance of stable isotope analysis are from those settings involving transitions to and/or intensification of consumption of domesticated plants having C_4 photosynthetic pathways from the earlier wild plants consumed that had C_3 photosynthetic pathways. For example, in the Americas the shift from C_3 (wild varieties of plants) to C_4 (domesticated varieties of plants) occurred with the shift to and intensification of maize agriculture (e.g., Ambrose, 1987; Harrison and Katzenberg, 2003; Larsen et al., 1992, 2007; Schoeninger, 2009; Tykot et al., 2006; Wright, 2006), in Europe and Asia the shift involving consumption of millet (Bonsall et al., 2004; Le Huray and Schutkowski, 2005; Murray and Schoeninger, 1988; Pechenkina et al., 2005, 2013; Svyatko et al., 2013; Tafuri et al., 2009; Yang et al., 2012), and in Africa the adoption of sorghum and millet (White & Schwarcz, 1994). The documentation is provided via determination of the ratios of the $^{13}C/^{12}C$ (expressed as $\delta^{13}C$) in the consumer's skeletal and/or dental tissues. These ratios vary according to the amount of C_3 vs. C_4 plants in diet. In this regard, C_4 plants have less negative $\delta^{13}C$ ratios than C_3 plants, which are reflected in the tissues of the consumers.

The documentation of stable nitrogen isotope ratios provides an essential picture of the kinds of plants and animals consumed in regard to their trophic level in local food webs. Organisms that are higher in the food chain are more enriched in ^{15}N than ^{14}N, thus producing relatively higher $\delta^{15}N$ values for herbivores than plants and for carnivores than herbivores. This opens up the possibility of documenting the amount of meat in diet (higher $\delta^{15}N$ values indicated more meat consumption than lower $\delta^{15}N$ values). Owing to the highly varied diets of many human populations where they are consuming plants, herbivores, and carnivores, their stable isotope signatures tend to track somewhere between those of herbivores and carnivores. This record is complex and is influenced by consumption of seafood and a myriad of other local circumstances, but has successfully documented patterns of dietary variation in a wide range of settings (e.g., Choy et al., 2010; Pearson, 2013; Prowse et al., 2005; Katzenberg and Weber, 2009; Larsen et al., 2001).

In addition to documenting the shift from foraging to farming, the stable isotope record has been invaluable in demonstrating the pattern of change in coastal settings where prior to agriculture, foods were often dominated by marine resources, but with the adoption of agriculture, foods quickly became largely terrestrial-based to include an emphasis on less marine or meat and more plant cultigens in diets. This has been especially well documented in the Pacific region a millennium after original settlement of some islands (e.g., Field et al., 2009), in Denmark (Jørkov et al., 2010; Richards et al., 2003; Tauber, 1981, 1986) and elsewhere (Lidén, 1995). The record shows that in at least some settings of Europe the foraging-to-farming (Mesolithic to Neolithic) was generally not a gradual process, but rather, occurred rapidly, perhaps within a century.

Wear on the chewing surfaces of teeth, ranging from microscopically-visible scratches, pits, and surficial textural changes (e.g., Krueger, in press; Teaford, 1991; Ungar et al., 2008) to highly-visible alterations in form and angle of macroscopically-visible wear can yield information about diet (e.g., Burnett, in press; Smith, 1984; Walker, 1978). In general, there is more severe tooth wear in forager populations than in farming populations. For a number of Old World settings, in addition to plants, animal products such as milk have been a food of major importance in Europe, providing an energy and nutritional resource for at least eight thousand years. Recovery and analysis of the whey protein ß-lactoglobulin preserves in calculus of teeth gives an accurate representation of this food source (Warriner et al., 2014).

Health implications of diet and dietary change in the foraging-to-farming transition

The implications of the shift from foraging to farming globally and locally, be it in Denmark, Egypt, eastern North America, or virtually anywhere else where the transition took place, are well-documented in human skeletal remains. But, before addressing that record, let's look at the issue from the point of view of *expectations* of what one would expect to see in people having diets dominated by cereal crops—for example, maize, millet, wheat, and rice. Fundamentally, poor health in the consumers of these plants is predicted by a suite of observations of living people from clinical, ethnographic, and other observational research. These cereal grains:

- are deficient in or missing one or more essential amino acids, such as lysine, isoleucine, or tryptophan;
- have inadequate iron, caused by either deficiency of iron and especially presence of phytate, which prohibits full availability of iron to body tissues for growth, development, and replacement (such as in bone tissue);
- are deficient in one or more vitamins (A, the group of organic compounds that include retinol, retinal, retinoic acid; B_1, thiamine; B_2, riboflavin; B_3, niacin; B_{12}, cobalamin; C, ascorbic acid; and others);
- have clear links with malnutrition, immunosuppression and reduced ability to resist local and general infection, and increased susceptibility to a variety of pathogens (viruses, bacteria);
- are carbohydrates, creating a cariogenic oral environment and increase oral infections, dental caries, and antemortem tooth loss;
- are characteristically associated with populations living in dense, crowded, and sedentary communities, resulting in water contamination by parasites (e.g., hookworm) and/or pathogenic bacteria (such as *Vibrio cholera*, the bacteria that causes cholera).

The impact of farming on health in past populations

The above short list of attributes of the grains cultivated and consumed by the people provides the record for the testing the hypothesis that agricultural dependence will result in poorer health. The record for testing the hypothesis has been building for the better part of the last four decades, beginning with a series of regionally-based bioarchaeological studies, especially in North America (e.g., Cook, 1984; Goodman et al., 1984; Larsen, 1982, 1984), and in other settings in Europe, Africa, Asia, and South America (various in Cohen and Armelagos, 1984). This record has subsequently expanded to include numerous other investigations (Klaus and Tam, 2010; Pechenkina et al., 2013; Roberts and Cox, 2003; Temple and Larsen, 2013; various in Steckel and Rose, 2002; Cohen and Crane-Kramer, 2007; Pinhasi and Stock, 2011). The study of thousands of human remains around the world reveals some highly consistent results, but certainly with variation (Larsen, 1995, 2006). Here, I

Figure 1. Dental caries in adult mandibular dentition from Ochsenfurt, Germany, dating to ca. AD 1300-1700 (individual 41). Note the loss of most of the tooth crowns of the right second premolar and right first molar. The right second molar was lost antemortem. Image courtesy of Leslie L. Williams.

present a brief summary of what bioarchaeologists have learned about health changes in the last 10 thousand years with respect to the foraging to farming transition and its later intensification. Bioarchaeologists employ a variety of measures of health and living conditions. For purposes of this paper, I focus on dental caries, periodontal disease, and periostitis to illustrate trends in these conditions as representing key aspects of health. (For discussion of other indicators, see Larsen, 2015.)

Some of the most consistent evidence showing clear evidence of health declines is revealed in study of dental caries, a disease process characterized by focal demineralization of dental tissues by acids produced by bacterial fermentation of dietary carbohydrates. The process usually commences in grooves and fissures of the chewing surfaces of unworn teeth, followed by engagement of the tooth crown generally, and in most extreme circumstances, loss of the crown, extending into or involving the entire tooth root (Figure 1). The basic gradient from low to high prevalence based on level of commitment to agriculture is straightforward, but the degree of rise varies considerably, in part owing to differences in age composition of comparative samples. That is, the longer someone is alive, the greater the chances of having caries. The

Figure 2. Antemortem tooth loss in adult mandibular dentition (individual 14) from Ochsenfurt, Germany, dating to ca. AD 1300-1700 (individual 14). Missing teeth–those lost prior to death–include the right first, second, and third molars. Image courtesy of Leslie L. Williams.

condition is also highly influenced by food preparation technology. Grains prepared into soft gruels will provide a relatively more cariogenic environment for the bacteria (e.g., *Streptococcus mutans*) that produce the acids that dissolve the tooth enamel and other dental tissues. Moreover, there is some evidence to suggest that some cultigens are relatively more cariogenic than other cultigens. For example, while certainly having cariogenic properties, rice may be less so than maize, millet, or wheat (see Domett and Tayles, 2007; Oxenham et al., 2006; Pechenkina et al., 2013; Pietrusewsky and Ikehara-Quebral, 2006). In the American Midwest, an earlier farming regime involving production and consumption of five domesticated native starchy plants 2000-4000 years ago–bottle gourd (*Lagenaria siceraria*), marshelder (*Iva annua* var. *macrocarpa*), sunflower (*Helianthus annuus* var. *macrocarpus*, and two varieties of chenopod (*Chenopodium berlandieri*) (Smith and Yarnell, 2009). These plants are cariogenic, but less so than maize (*Zea mays*), the domesticate that was introduced to societies in Eastern North American beginning by A.D. 800 or so (Smith, 1989).

Dental caries is a harbinger of other oral problems, including especially the general suite of outcomes of pathogenic oral bacteria that cause dental caries but are also implicated periodontal disease

Figure 3. Periostitis in adult tibia from Ochsenfurt, Germany, dating to ca. AD 1300-1700 (individual 76). Note the irregular surface and buildup of bone owing to processes relating to infection. Image courtesy of Leslie L. Williams.

(periodontitis), a condition that involves the accumulation of bacteria (plaque) on teeth and subsequent inflammation of the gums, loss of tissues connecting teeth to jaws, eventually resulting in the exfoliation and loss of teeth (Figure 2). Periodontitis is common in industrialized countries today, including the United States and most countries in Europe. It is becoming increasingly common in the developing world with the wider availability of low-quality carbohydrates. Like dental caries, the bioarchaeological record for periodontitis and antemortem tooth loss reveals a higher prevalence in prehistoric farmers than foragers (Bennike and Alexandersen, 2007; Clarke et al., 1986; Klaus and Tam, 2010; Nelson et al., 1999; and many others).

Dental caries and periodontitis have profound implications for general health, both for the individual and for the population as a whole. That is, a wide range of clinical and epidemiological investigations document the association between poor oral environment in earlier life and the association with increased mortality, and susceptibility to chronic, systemic health conditions such as cardiovascular disease and respiratory infections in later life (Buhlin et al., 2003; DeStefano et al., 1993). For past populations, there is a growing record for an increased risk of death for those having poor oral health. For example, individuals with dental caries and periodontal disease have an increased risk of death in Medieval populations (DeWitte and Bekvalac, 2010).

Another consistent pattern documented by bioarchaeologists in comparison of foragers and farmers or earlier and later farmers is an increase in periosteal reactions or periostitis in a wide variety of settings (Cunha et al., 2007; Danforth et al., 2007; Douglas and Pietrusewsky, 2007; Garner, 1991; Gold, 2004; Hoyme and Bass, 1962; Klaus and Tam, 2009; Larsen et al., 2007; Márquez Morfín and Storey, 2007; Martin et al., 1991; Pechenkina et al., 2007; Stodder et al., 2002). In the Dickson Mounds series from Illinois, the prevalence doubled from 31% to 67% of individuals affected in comparison of later farmers with earlier farmers (Goodman et al., 1984). Periosteal reactions are represented as bone plaques with irregular elevations of bone surfaces. The underlying production of new bone is caused by compression and stretching of blood vessels by pus, blood, and/or a variety of other factors and is the follow-up response of the bone as a healing mechanism (Weston, 2008) (Figure 3). The tibia is the most commonly affected bone, perhaps owing the minimal soft tissue separating the skin from bone and increased susceptibility to local infection from bacteria (e.g., *Staphylococcus*) entering wounds in this area of the body.

Other factors may be involved, but most periosteal reactions are likely caused by local infection. Thus, in settings where populations are sedentary and closely aggregated, this creates the circumstances for accumulation of debris, poor living conditions, and decreased sanitation, all the ideal circumstances for the increased chances of infection in circumstances involving traumatic injury and wounding. Moreover, under circumstances where nutritional quality is reduced in farming populations, the synergy between infection and poor nutrition likely exacerbates the ability of immune system to resist the infection. That is, there is a synergy between infection and malnutrition (Keusch and Farthing, 1986; Scrimshaw et al., 1968)—malnourished individuals are less resistant to infectious pathogens and are rendered more susceptible to infectious disease; conversely, infection worsens nutritional status. Overall, the bioarchaeological record provides strong support for the epidemiological model that an increase in population size and density contributes to a decline in community health at least as it is represented by periosteal reactions in comparison of foragers and farmers and less intensive with more intensive farmers. Similarly, a number of Old World and New World settings display clear evidence in the skeletal remains for specific infectious diseases, such as nonveneral (endemic) syphilis and tuberculosis (e.g., Bruwelheide et al., 2010; Cole and Waldron, 2011; Lambert, 2006; Marden and Ortner, 2011; Mays et al., 2003; Powell and Cook, 2005; Roberts and Manchester, 2005; Sandford et al., 2002), with an especially prominent record in Eastern North America (e.g., Danforth et al., 2007; Hutchinson, 2004; Hutchinson and Norr, 2006; Lambert, 2000; Smith, 2008; Powell, 1990, 1994; Powell and Cook, 2005; Wilson, 2005).

Much of the record discussed in this paper pertains to the Neolithic and other prehistoric settings involving early farmers. The *European History of Health Project*, a collaboration of a group of 75 European, Canadian, and American biological anthropologists, has documented oral and skeletal pathology from a data set of some 75,000+ skeletons, both on data previously and newly collected for dental caries, antemortem tooth loss, and periostitis (Wittwer-Backofen et al., 2009; Marques et al., 2009). Preliminary analysis reveals increases that continue during the Medieval period when populations are highly dependent on cereal grains and live in crowded community settings. The elevation in caries and antemortem tooth loss become especially elevated in the pre-industrial and industrial periods, likely in part fueled by access to refined sugar (Larsen et al., 2012; Wittwer-Backofen et al., 2009).

So, if farming and focus on agricultural products—especially cereal crops—are so bad, then how is it that human population size has so dramatically increased? In other words, there would appear to be a contradiction between the quality of diet and the explosion in human population size. In fact, analysis of the skeletal record indicates that birthrates and population growth were fueled by increasing fertility that accompanied the foraging-to-farming transition (Bocquet-Appel, 2002, 2011; Buikstra et al., 1986; Larsen et al., 2007; Milner et al., 1989), likely made possible by the availability of foods promoting earlier weaning and hence, reduced birth spacing (Buikstra et al., 1986; Lambert, 2009). Like current populations in developing nations where there is a coupling of high birthrates and poor nutrition, the study of past populations underscores the point that survival to reproductive years may not necessarily be healthy. Nonetheless, survival and reproduction can support a growing population as long as enough resources–good or bad–are available.

Conclusion

The key findings in assessing the impacts and outcomes on human health in the transition from foraging to farming and later intensification of farming include the following:

1. Diet and nutrition are key elements of quality of life and living conditions generally;
2. In comparison with prehistoric foragers, early farmers show a general pattern of declining health, but with regional variation;
3. While early farming may have been generally deleterious to health, rice farming may have been less so than maize or wheat farming owing to the lesser amount of phytate in the former than the latter.
4. Post-Neolithic farming involves intensification of earlier patterns and origins of evolving superfoods–wheat, maize, and rice–in the 21st century; our foods and health outcomes today have their roots deep in the human past. The development of poor oral health beginning 10,000 years ago laid the foundation for continuing oral health issues, and may represent the conditions necessary for the origins of a range of chronic health conditions, including cardiovascular disease and other circumstances resulting in earlier death. That is, in currently living populations those with poor oral health are predisposed to the development of chronic health issues in later life. It is likely that the same holds true for past populations.
5. The tide of poor health has turned in some of the modern world, made possible by improved health care, appropriate hygiene, and better nutrition, especially for upper echelons of society. Unfortunately, today as in the past, better conditions are available primarily for the minority of the population having access to these developments.

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