Bioarchaeology of Neolithic Çatalhöyük reveals fundamental transitions in health, mobility, and lifestyle in early farmers

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The transition from a human diet based exclusively on wild plants and animals to one involving dependence on domesticated plants and animals beginning 10,000 to 11,000 y ago in Southwest Asia set into motion a series of profound health, lifestyle, social, and economic changes affecting human populations throughout most of the world. However, the social, cultural, behavioral, and other factors surrounding health and lifestyle associated with the foraging-to-farming transition are vague, owing to an incomplete or poorly understood contextual archaeological record of living conditions. Bioarchaeological investigation of the extraordinary record of human remains and their context from Neolithic Çatalhöyük (7100–5950 cal BCE), a massive archaeological site in south-central Anatolia (Turkey), provides important perspectives on population dynamics, health outcomes, behavioral adaptations, interpersonal conflict, and a record of community resilience over the life of this single early farming settlement having the attributes of a protocity. Study of Çatalhöyük human biology reveals increasing costs to members of the settlement, including elevated exposure to disease and labor demands in response to community dependence on and production of domesticated plant carbohydrates, growing population size and density fueled by elevated fertility, and increasing stresses due to heightened workload and greater mobility required for caprine herding and other resource acquisition activities over the nearly 12 centuries of settlement occupation. These changes in life conditions foreshadow developments that would take place worldwide over the millennia following the abandonment of Neolithic Çatalhöyük, including health challenges, adaptive patterns, physical activity, and emerging social behaviors involving interpersonal violence.

Neolithic farmers | Turkey | bioarchaeology | health | lifestyle

The shift from production, consumption, and dependence on foods hunted, gathered, and collected to foods derived from farming and herding that started some 10,000 to 11,000 y ago in Southwest Asia was among the most fundamental and impactful events in human evolution, leading to unprecedented changes in subsistence practices, dietary composition, and adaptation (1–4). This transformation in how humans acquire food resulted in dramatic behavioral adaptations effecting alterations in labor, community size, and population density (1, 5–7).

Many authorities regard the transition from foraging to farming as a long, slow process (8). However, when viewed in the context of the previous 6 or so million years of hominin evolution or the 200,000-y history of *Homo sapiens*, the foraging-to-farming transition commencing at the Pleistocene–Holocene boundary occurred in an extraordinarily short time frame, and subsequently emanated from at least a dozen primary centers of domestication in East and West Asia, Africa, New Guinea, North America, and South America (3, 9). This transition in living circumstances and the manner in which humans acquire food is especially important because it led to economic and demographic patterns (e.g., reliance on specific food sources, increase in population size) that not only formed the foundation for later social and biocultural developments (e.g., emergence of complex hierarchical societies) but also represents the basis of many of today's foods and their associated health and behavioral outcomes for human consumers. That is, health and lifestyle changes involving increases in population-dependent infectious disease in particular and elevated morbidity in general, along with dramatic decreases

Significance

Bioarchaeological investigation of human remains from Neolithic Çatalhöyük, Turkey, contributes to a growing body of data documenting population dynamics, health, and lifestyle of early farmers in Holocene settings in the Near East and globally. The extensive archaeological context of foodways, material culture, housing, environment, ecology, population structure and size, social interaction, and community living informs interpretation of the bioarchaeological record representing nearly 1,200 continuous years of community life. This record presents biological outcomes and comprehensive understanding of the challenges associated with dependence on domesticated plants and animals, the labor involved in acquiring food and other resources, impacts of settled community life on health and well-being, and evolving lifeways to the present day.

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See Profile on page 12593.

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in activity-related skeletal robusticity, are shaped in important ways by the circumstances originating with early plant and animal domestication starting locally 10 millennia ago and culminating globally today. Ultimately, the foraging-to-farming transition created the conditions leading to the so-called "diseases of civilization" (e.g., cardiovascular disease, cancer), dental–oral infections, and a range of crowd-based infectious diseases and systemic conditions killing millions at various points in human history and for the foreseeable future (10, 11).

Ten millennia or so ago when farming practices commenced, only a miniscule proportion of the world population included domesticated plants and animals in their diets for the first time. To one extent or another, all of the nearly 8 billion members of the world population in 2019 are dependent on domesticated foods for survival. It behooves us, therefore, to comprehend the origin, evolution, and impact of key circumstances in interpreting health and lifestyle of the past to better understand strikingly similar patterns in life conditions in the twenty-first century.

Plant and animal domestication—the defining elements of the Neolithic period—began in the Fertile Crescent of Southwest Asia *ca.* 10,500 yBP (4, 12–14). By the second half of the ninth millennium cal BCE, farming of cereal crops—e.g., emmer and einkorn wheat—spread eastward onto the Anatolian plateau in Turkey (15). The farming communities of the Early Holocene Anatolian plateau are key settings for understanding the Neolithic transition in Europe, largely due to the central role of Anatolia as a source of people, subsistence practices, lifestyle, and ideas that spread to Europe over the course of the next several thousand years (15).Within a few millennia following the arrival in Europe of the Neolithic "package"—domesticated plants and animals, increased social complexity, long-term community settlement, and expanding population size—much of western Asia and Europe would feature many communities dependent, to some degree, on products derived from farming (16).

The impressive expansion of regionally based bioarchaeological investigations of early farmers worldwide provides a growing global profile of health and lifestyle changes (1, 5–7, 17). The bioarchaeological record documents a general pattern of elevated skeletal and dental morbidity in early farmers relative to their ancestral foragers (e.g., increased systemic and oral infectious disease). In a number of settings, skeletal changes include reduced stature and body mass and behaviorally related skeletal adaptations reflecting declining mobility (18). Although these emerging trends are important, only rarely has it been possible to document and interpret key details of living conditions, sociocultural contexts, and behavioral circumstances within and over the long duration for a single, large evolving community. Ideally, such a community would 1) be well-defined temporally, providing an opportunity to track key biocultural developments (changes in diet, living conditions, and social and economic organization) over many generations, and 2) permit a detailed overview of the relationship between humans and their biological and sociocultural environment. These conditions can be addressed only via large-scale, long-term projects addressing common issues from multiple research avenues.

One such community is Neolithic Çatalhöyük, located in the Konya Plain on the Anatolian plateau of south-central Turkey (Fig. 1). Çatalhöyük includes the material remains of one of the

Fig. 1. Regional map of Turkey and the Mediterranean basin showing location of Çatalhöyük. Image courtesy of Camilla Mazzucato (Stanford University, Stanford, CA).

most well-known Neolithic megasite communities and is represented by a large tell measuring 13 ha with nearly 21 m of stratified deposits spanning 1,150 y of continuous occupation (*ca.* 7100–5950 cal BCE) (19). For Southwest Asia, in particular, and the Old World, in general, Çatalhöyük contains an extraordinarily well-contextualized record of Neolithic life, in large part owing to its comprehensive and detailed archaeological documentation, including an unprecedented record and analysis of environment and landscape, funerary contexts, living circumstances, material culture, animal and plant remains, and associated human remains. The following builds on earlier initial bioarchaeological study of this setting (20), and presents data, expansion of earlier datasets, and insights into life and living circumstances in this Neolithic setting.

The Community: Discovery and Context

The discovery and excavation of Çatalhöyük on the Konya Plain of south-central Turkey by James Mellaart revealed an enormous settlement with an extraordinary and unexpectedly elaborate material culture, including wall paintings, stone-carved figurines of humans and animals, many graves containing well-preserved human skeletal remains, stratified sequences and densely clustered houses, and other key attributes of an emerging and evolving complex society (21–23). Several decades after Mellaart completed his fieldwork in the mid-1960s, the 25-y Çatalhöyük Research Project (1993–2018) directed by Ian Hodder was established (24). Over the course of the latter project, scores of researchers comprising different teams of specialists collaborated on excavation and study that collectively address central issues pertaining to population; animal, plant, and human biology; and the social and cultural dynamics of this uniquely situated Neolithic community (24).

Çatalhöyük's funerary record is represented by an especially large and well-documented assemblage of human skeletal remains of 470 complete individuals in stratified primary burial contexts, as well as the partial remains of an additional 272 individuals recovered from secondary and tertiary burial contexts (Fig. 2). In addition to encompassing the entire demographic spectrum from neonate through elderly adulthood, the Çatalhöyük series of human remains is part of a funerary record that is among the largest and most thoroughly contextualized for the earlier Holocene of Southwest Asia. Most of the burials are of single individuals usually tightly flexed and interred in burial pits, accompanied at times with material culture. Most of the graves are located beneath house floors, including the majority of adults in rectangular clay-constructed platforms along the northern and eastern walls of the central rooms of houses (25). The funerary context, including burial treatment, form, and location, is relatively uniform throughout the occupation of the site, and suggests a society with a clear sense of the community of the deceased ancestors lying beneath. Toward the end of occupation, however, secondary inhumations overtake primary inhumations as the predominant burial treatment, and the overall number of burials occurring within houses is greatly diminished. The purposeful reopening of graves, retrieval, and possible circulation of skeletal elements (especially but not limited to crania and mandibles) (26) suggests, moreover, that the living inhabitants of the Çatalhöyük community shared a common space with their deceased ancestors, both physically and symbolically.

Addressing questions about lifestyle and quality of life in such a large Neolithic settlement provides a unique perspective for developing an understanding of the level of commitment to production and consumption of domesticated food products, the amount of labor and workload demands invested in feeding and sustaining the community over the course of its occupation history, and the types of social and behavioral patterns associated with these practices. The period of 7,000 to 9,000 y ago is a critical time for this community, representing the inception and evolution of sedentism, labor demands and lifestyle, dependence on domesticated plant and animal food sources, climate fluctuations, and growth and crowding in a protourban setting.

Fig. 2. Çatalhöyük burial F.2232 is a headless young adult female (13162) with a fetal skeleton (13163; arrow) in her abdominal region. The 2 individuals were the first in a sequence of interments in a burial pit in the east platform of Building 60, dating from the Late Period occupation at Çatalhöyük. Skull removal was an element of mortuary treatment in this Neolithic setting. Image credit: Jason Quinlin. Image courtesy of the Çatalhöyük Research Project.

The Rise, Peak, and Decline of the Çatalhöyük Community

For purposes of temporal comparisons for tracking key life-course events in the Çatalhöyük community, we subdivide the 1,150 y of occupation into 3 temporal periods: Early Period (7100–6700 cal BCE), Middle Period (6700–6500 cal BCE), and Late Period (6500–5950 cal BCE). The community began as a small settlement, likely consisting of a few mud-brick houses occupied by a small group of adults and children. At its initial settlement, Çatalhöyük was likely similar to the earlier and short-lived community located 9 km to the north at Boncuklu Höyük (15). Çatalhöyük houses typically had a lifespan of several decades or more (27–29). Once a house was abandoned, the floor surface was cleaned, the roof and walls were largely removed, and a new house was often built on the same footprint as the old house. Multiple construction phases occurred, sometimes involving 4 or more rebuilds of a house following an abandonment–rebuild sequence.

Following its founding, the Çatalhöyük community grew, reaching a peak population size of ~3,500 to 8,000 individuals in the Middle Period (27). Based on house number, size, and density,

the Middle Period saw a rapid increase in population size and the highest level of crowding in the history of the community (27). This development reversed course in the Late Period, resulting in considerable population reduction and dispersal, and culminating in abandonment and dispersal of Neolithic Çatalhöyük by the remaining members of the community and the establishment of a new settlement nearby in the Chalcolithic period (24).

The archaeological reconstruction of population agglomeration and growth in the Middle Period and marked decline into the Late Period is consistent with analysis of the age-at-death composition and profile of the human skeletal series. Analysis of age composition via the juvenility index as a proxy for fertility (30) documents a pattern of increase in fertility and birthrate in the Middle Period, fueling the growth of the community, cresting *ca.* 6610–6250 cal BCE, followed by a decrease in fertility and birthrate contributing to decline in population size in the Late Period (31, 32). Although birthrate decline contributed to population reduction in the final centuries of the settlement, the archaeological record also suggests dispersal and relocation of community members elsewhere contributing to population decline (33).

Some of these changes likely reflect impacts of climate fluctuations, aridification, and associated stress, thus driving population decline in the Neolithic Near East (34), including at Çatalhöyük and the Konya Plain (35, 36). Moreover, the large size of the population in the Middle Period would have negatively influenced the local environmental setting, such as reduced availability of wood sources for building materials and fuel, and increasing need for expansion of caprine grazing lands.

The interiors of Çatalhöyük houses share a number of characteristics that inform our growing understanding of the conditions of health and well-being in the community (37). For example, interior walls and floors were plastered and periodically replastered many times with white calcareous silty clay (38). Excavation of houses shows that floors were relatively debris-free. However, microstratigraphic analysis of house walls, floors, burials, and other contexts shows the presence of an appreciable volume of animal and human fecal matter (39–41). Moreover, refuse areas, latrines, and pens for domestic animals were in close proximity to houses. Analysis of soil samples produced remains of parasite eggs and parasite egg fragments (39). Sheep are a common intermediate host for parasites before human infestation (42) and represented a major public health problem, much as they do in many settings worldwide today. These circumstances indicate that hygiene and health were likely compromised among community members. The crowded living conditions peaking in the Middle Period would have promoted the transmission of pathogens and increased chances of localized tissue infections deriving from cuts and abrasions of the skin leading to subperiosteal bone reactions. In a similar fashion, ongoing commitment to production and consumption of plant carbohydrates would have played a central role in promoting oral pathological conditions, such as dental caries and periodontal disease, commonplace in prehistoric farming societies (11).

Çatalhöyük Diet and Population Dynamics

The dataset used to track the history of the Çatalhöyük community was developed by a diverse array of expertise in archaeology, biogeochemistry, geology, ecology, and materials science, as well as bioarchaeology. The collective results from these sources of inquiry provide an interpretive framework for documenting life and living conditions in this important period of human evolution. The results provide significant insights about the biological impacts of sedentism and permanent settlement, increased social complexity, and the navigation of a varied landscape for the acquisition of food and other resources, much of which were derived from farming.

Analysis of an extraordinary volume of archaeobotanical remains from domestic and other settings at Çatalhöyük provides a record of production, preparation, and consumption of cereal crops, mostly glume wheat (emmer and einkorn) and other crops, including bread wheat, barley, rye, peas, lentils, and nondomesticated starches and other plant species (43–45). Cereals were the core of Neolithic foodways, in part owing to the ability to store grains and to later prepare them as a food source. At Çatalhöyük, cereals were pounded and ground and prepared into breads and porridges (46). Consumption of soft-textured food often promotes dental caries and periodontal infections.

A remarkably comprehensive record of animal remains shows the dominance of domesticated caprines (especially sheep, but also goats) throughout the entire history of community subsistence practices. In the later occupation, domesticated cattle were introduced, forming a part of the diet (47, 48). Other nondomesticated animal sources of protein included asses, hares, deer, fish, and shellfish, with all showing evidence of butchery (49).

The increasing diversity of stable isotope ($\delta^{18}O$, $\delta^{15}N$, $\delta^{13}C$) values derived from sheep skeletal remains and changing patterns of microwear on occlusal surfaces of their teeth reveal a substantial increase in the grazing range and movement of herds over greater distances from the community and across the Konya Plain (50–52). This changing distribution of herding activities would have likely involved an increase in mobility for members of the community responsible for herding (and see below). Although it may be the case that sheep herding extended to the surrounding uplands, $^{87}Sr/^{86}Sr$ isotopic signatures indicate the exclusion of the uplands ecozone (53). Rather, the isotopic record presents herding activities that are largely tied to the plain surrounding the community, a pattern consistent with relatively localized crop and sheep management practices.

Paleoenvironmental reconstruction of the Çatalhöyük landscape at the time of the original settlement in the earlier Holocene coincides with a shift from humid to dryland conditions. This reconstruction makes a compelling case that localized areas in the floodplain surrounding the community were sufficiently dry for crops, as well as for exploitation of wood and clay resources (36, 54, 55).

The above record of archaeobotanical and archaeozoological analysis reveals a clear commitment to production and consumption of domestic food resources (51, 56, 57). Stable carbon isotope ratios ($\delta^{13}C$) document the kinds of plants consumed by community members, whereas stable nitrogen isotope ratios ($\delta^{15}N$) give a record of trophic level and the relative importance of animal sources of food. Stable isotope analysis of the Çatalhöyük inhabitants shows important dietary variation in the community that corresponds with 1) temporal patterns, 2) the life course from birth through adulthood, 3) sex, and 4) neighborhood and individual households. These comparisons show a general increase in nitrogen isotope ratios, peaking in the Late Period. Moreover, there is a strong similarity in values between females and males, indicating a similarity in the diets of women and men. Combined with the archaeozoological evidence, the increase in nitrogen stable isotope ratio values is consistent with increased consumption of animal sources of protein, especially derived from domesticated caprines (51). We speculate that the increased herding range—from relatively local to farther and farther from the community—reflects a heightened preference for caprine sources of protein, or perhaps increased demands for caprine production in response to the growing size of the community, especially at peak population size during the Middle Period.

The isotopic analysis of skeletal remains presents a life-course pattern of earlier- and later-life dietary variation, commencing with weaning at about 3 y of age, followed by dietary transitions associated with childhood and advancing age in adulthood. Diets

of adult males and females are broadly similar. Individuals buried within the same houses, however, have isotopically different diets (56). This finding is consistent with a kinship pattern whereby inhabitants of houses were not all biologically related. It has long been assumed that the remains of adults and children interred in house floors were relatives, with juveniles being the children of adults and grandchildren of older adults, all functioning as a social household unit. However, the diversity of diets within households, coupled with intrahouse biodistance analysis of dental phenotypic variation, indicates that social organization was likely not kin-based; individuals interred in the same house were largely unrelated (58). The lack of dietary and genetic patterning is more consistent with social relationships within households, in particular, and the community, in general, that are based on practical kinship and not biological kinship (59).

On a larger regional scale, however, analysis of dental phenotypic variation of Çatalhöyük and 2 other central Anatolian Neolithic communities—Aşıklı Höyük and Musular—indicates overall similarity, suggesting regionally based variation (60). Moreover, within Çatalhöyük, there is a pattern of lower dental phenotypic variation in males than in females which documents the likelihood of patrilocal postmarital residence (61), an outcome having implications for movements of people, patterns of gene flow, and the structuring of population based on women moving into the community.

Sustaining the Çatalhöyük Community: Workload and Mobility in Acquiring Food and Other Resources

Skeletal morphology associated with both the level of workload and patterns of mobility provides a compelling approach to characterizing activity and lifestyle deriving from habitual activities involving lifting, carrying, and other strenuous physical behaviors. In particular, biomechanical parameters of skeletal morphology offer answers to questions about the level and kinds of activity needed to sustain the life of the community, including mobility involving routine travel over long distances. Analysis of lifestyle is derived from a biomechanical model based on simple beam theory developed by mechanical and civil engineers for designing bridges, buildings, and other structures and assuring the ability of these structures to resist heavy loads (62, 63). The model is based on the premise that the magnitude of stresses in a cross-section of a beam is related to the distribution of material relative to the central or "neutral" axis of such structures. That is, the greater the distance of material measured from its central axis, the stronger the section and the greater its ability to resist bending and torsion. Preferential distribution of material in a particular plane, such as in an I-beam, leads to greater strength and rigidity in that plane (30, 63). Unlike I-beams, however, bone remodels during growth and development to maintain its functional integrity over the life course.

This biomechanical approach to assessing workload and activity addresses long-standing questions about individual and population patterns of lifestyle changes over both short and long timescales, and general patterns of adaptation as they are represented in skeletal morphology of the femoral diaphysis. In life, the midshaft of the human femur is subjected to anteroposterior (A-P) and mediolateral (M-L) bending loads. Because lower limbs move primarily forward and backward during locomotion, A-P loading exceeds M-L loading during movements such as walking and running. Thus, for individuals engaged in long-distance travel or elevated levels of mobility, the A-P bending forces are relatively greater than for individuals who are sedentary. The most relevant biomechanical variables for assessing bone response to such loadings are the section moduli Z_x and Z_y, representing A-P and M-L bending strength of the bone, respectively. The ratio of Z_x/Z_y can be used as an index of mobility, since long-distance travel results in relatively more A-P bending than M-L bending (30, 64). Thus, populations engaged in high levels of mobility have relatively higher Z_x values and Z_x/Z_y ratios than populations that are relatively sedentary (30, 63). At Çatalhöyük, cross-sectional geometric analyses of section moduli show both the changing patterns of Z_x/Z_y through time among adults and their developmental origins among juveniles, reflecting temporal increases in relative bone strength and mobility (Fig. 3) (65, 66).

These findings are consistent with an environmental explanation involving higher levels of labor and mobility in the later periods at Çatalhöyük. Moreover, they suggest participation by children in activities involving labor and mobility. The record shows increased mechanical demands as well as increased travel distance on a daily basis by both juveniles and adults in comparisons of the Early, Middle, and Late periods. These results are central to addressing competing hypotheses regarding level of labor, travel distance, and mobility in accessing food and other resources during the course of the settlement occupation. Moreover, the increasing mobility marks a dynamic change in lifestyle in response to increased travel demands necessary to access food and other resources and a wider geographic area for herding caprines.

Thus, the biomechanical evidence is consistent with isotopic evidence showing an increasing caprine herding range in later periods (53). These behavioral adaptations are likely responses to reduced availability of resources locally and the expansion of the range of activity involving food acquisition regionally, circumstances perhaps exacerbated by environmental change involving an increasingly drying landscape coupled with overexploitation of plants and animals (33, 48, 55). While climate change may have been an element in determining resource distributions and herding practices (45, 67), the record of population reduction and dispersal speaks to additional external forces, perhaps involving multiple causes such as social circumstances and living conditions. When viewed in the context of the archaeological record, biomechanical and biogeochemical data suggest a temporal depletion of resources farther and farther from the community and a shift in herding practices involving increasing long-distance travel. Regardless of the specific cause, however, the biomechanical record documents both increased workload and increased mobility for both juvenile and adult members of the community over the duration of the community.

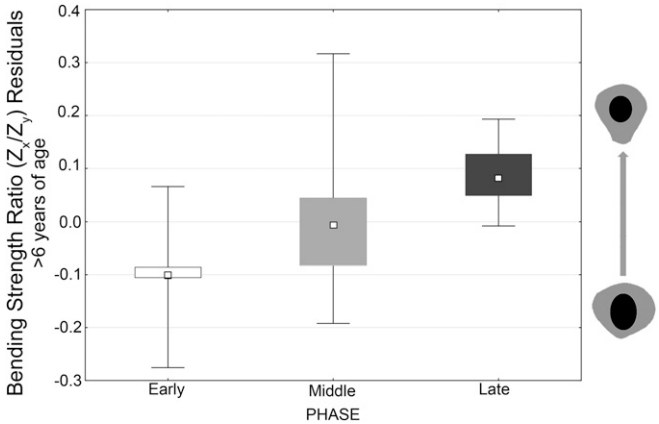

Fig. 3. (*Left*) Femoral middiaphyseal cross-sectional bending strength ratio (Z_x/Z_y) for Çatalhöyük 6- to 20-y-olds. Values increase from the Early to Late periods, reflecting temporal increase in mobility and bone strength for juveniles over the history of the community. Open square, median; box, 25 to 75%; whisker, min-max. The image at *Right* shows the cross-sectional shape changes representing these behavioral adaptations.

Growth and Development of Çatalhöyük Community Members: Implications for Health in Population Crowding and Nutritional Challenges

The transition to and the growing dependence on farming over the course of the Holocene came with clear health costs for human societies around the world (1, 2, 5, 7, 68). The close proximity of people to domesticated animals and to animal and human waste and the nutritional deficiencies of diets based on plant carbohydrates created challenges to normal growth and development. Assessment of health based on growth and development of the dentition and skeleton matches the record from other archaeological settings showing moderate growth instability in response to physiological stress (30). That is, virtually all Çatalhöyük individuals possess linear enamel hypoplasias (LEH) on their permanent canines, suggesting that childhood episodes of physiological instability were a ubiquitous occurrence throughout the duration of the community. This pattern is consistent with expectation for individuals drawn from settings having poor living conditions in other Old World archaeological contexts (30) and in living populations (69, 70). Similarly, the record of dental fluctuating asymmetry, whereby teeth and skeletal structures that are normally bilateral mirror images of each other develop differently under conditions of environmental instability (71–73), shows only a slight temporal decline in the Late Period when population size and crowding had diminished considerably (32). On the other hand, children in the Late Period with LEH have smaller skeletal size for age than in the Middle Period, a factor that may reflect somewhat less buffering from negative living conditions (74). However, for all juveniles, both with and without defects, there is no change in juvenile stature over the duration of community history (65).

The record of developmental instability, however, had limited impact on skeletal growth in this setting. In this respect, Çatalhöyük adult stature is normal compared with other Neolithic populations in Europe and the Near East, and early ontogenetic patterns of growth in stature and body mass match the patterns documented in well-nourished modern populations (31, 64, 65, 74, 75). Thus, while the community was clearly challenged via multiple sources of physiological stress, the available resources were sufficient to maintain relatively normal growth and development among the members of the community.

Consequences of Crowding: Infection, Infectious Disease, and Pathogen Exposure

Indicators of skeletal infection and infectious disease in general offer the opportunity to address central questions relating to the challenges posed by living in a crowded environment and adopting a diet based on plant carbohydrates. The global bioarchaeological record shows a tendency for elevated prevalence of subperiosteal reactions involving lower limb (i.e., tibia) diaphyses in populations of farmers relative to those of foragers (30, 76). This evidence suggests that most lesions result from infection caused by localized bacterial pathogens (30). The Çatalhöyük series shows a temporal decline in subperiosteal reactions from 33 to 26 to 19% in the Early, Middle, and Late periods, respectively. The finding that the highest value is in the Early Period, a time when population was small relative to the Middle Period, appears at odds with expected associations between population density and environmental stress. On the other hand, the Early Period contains clear circumstances of poor living conditions, including growth in population size and the presence of animal pens and refuse areas exposing potential human hosts to pathogenic organisms. Like the Early Period, the Middle Period provides an outcome observed in a wide range of archaeological settings showing a positive association between elevated lesion prevalence and increased population density (1, 7, 30, 77). The archaeological and paleodemographic record of reduced population size and crowding in the Late Period likely explains the significant reduction in prevalence of subperiosteal reactions during this final phase of settlement.

Changes in community structure involving an increase in population size and density in the Middle Period within the larger context of increasing sedentism present increased opportunities for the transmission of pathogenic microbes from person to person. Infectious diseases caused by pathogenic microorganisms, including bacteria, parasites, and viruses, have long challenged human health. Indeed, many such microorganisms and the diseases they cause have a long evolutionary history (78, 79). Given the relatively small size of social groups, dispersal of population, and minimal permanence of settlement until the later Pleistocene or Early Holocene, it is unlikely that there would have been transmission of pathogens from person to person in a continuous fashion (11, 80). The appearance of densely settled megasite communities characterized by permanent, year-round habitation, population crowding, minimal sanitation, and narrow, carbohydrate-based diets provides ideal conditions for the evolution, adaptation, and transmission of pathogens (10, 11).

Analysis of oral health in the Çatalhöyük population provides a significant record of morbidity. That is, the elevated levels of dental caries (81), a disease process characterized by focal demineralization of dental hard tissues due to by-products produced by bacterial fermentation of dietary carbohydrates (starches and sugars), signals a clear commitment to production and consumption of cereal crops by the majority of the community. This finding matches a pattern of increase in prevalence of carious teeth in farming populations in a wide range of settings globally, with perhaps less cariogenic properties for some cultigens than others (30).

Consistent with a community committed to the production and consumption of domesticated plant carbohydrates, there is an elevated prevalence of dental caries in both adult females (Early, 10.5%; Middle, 12.9%; Late, 10.4%) and adult males (Early, 9.7%; Middle, 10.0%; Late, 11.0%) (81). These values reflect a dietary focus on domesticated plant carbohydrates throughout the history of the community, and document a somewhat greater lifetime consumption of cultigens in women versus men.

The general pattern of health, living conditions, and behavior at Çatalhöyük and other Neolithic settings of western and eastern Asia is similar in many respects to that documented during the origins and development of agricultural-based subsistence practices that would later take place in Europe, North America, and South America (30). This is not to say that sedentism and domestication are unequivocally associated with the challenges observed at Çatalhöyük and elsewhere in Southwest Asia. In this setting, for example, while subperiosteal reactions are well represented, there is an absence of density-dependent infections such as those associated with mycobacterial disease (e.g., tuberculosis and leprosy) (11). There are, however, clear tendencies in many localities globally that share similar outcomes, responding especially to the poor nutritional quality of domesticated plants, population sedentism, and the consequences of living in larger, more densely populated communities.

Living in a Crowded Community: Assessing Violence and Interpersonal Conflict

Analysis of cranial injuries from archaeological contexts provides a means for testing the hypothesis that life in crowded, sedentary communities promotes interpersonal violence (82–85). During the Neolithic of Anatolia and Southwest Asia, generally, the social circumstances of interpersonal violence appear to have been highly variable (86, 87). Potential triggers of violence and common contexts for its presence include increasing intracommunity and intercommunity resource competition, population crowding, social/psychological stress, and other circumstances that are socially and culturally mediated.

Table 1. The life history of the Çatalhöyük community: The bioarchaeological record

Inference	Evidence	Early Period 7100–6700 cal BCE	Middle Period 6700–6500 cal BCE	Late Period 6500–5950 cal BCE
Birth rate	Juvenility index	Low	Increase	Decline
Living environment	Animal and human fecal matter and parasites	Poor	Poor	Poor
Domesticated sources plant carbohydrates in diet	Carbon isotope ratios	Present	Present	Present
Animal sources of protein (caprines) in diet	Nitrogen isotope ratios	Elevated	Increase	Increase
Unrelated persons interred within households	Carbon and nitrogen stable isotope ratios	Variable	Variable	Variable
Unrelated persons interred within households	Dental phenotypic variation	Variable	Variable	Variable
Distance of herding from community	Sheep stable isotope ratios	Local	Increase	Increase
Distance of herding from community	Sheep tooth microwear variation	Present	Increased variation	Increased variation
Adult mobility and workload	Long bone cross-sectional geometry	Low	Increase	Increase
Juvenile mobility and workload	Cross-sectional geometry	Elevated	Increase	Increase
Enamel development disruption	Enamel defects (hypoplasia)	Ubiquitous	Ubiquitous	Ubiquitous
Physiological stress	Dental fluctuating asymmetry	Present	Increase	Decrease
Body size/development	Growth patterns in body size	Normal	Normal	Normal
Density-dependent specific infectious diseases	Diagnostic pathology (e.g., tuberculosis)	Absent	Absent	Absent
Prevalence of localized skeletal infection	Subperiosteal reactions	Substantial	Decrease	Decrease
Prevalence of oral infection	Dental carious lesion prevalence	Substantial	Substantial	Substantial
Intracommunity Interpersonal violence	Cranial depressed fractures	Present	Increase	Increase

The Çatalhöyük community presents a compelling record of elevated levels of interpersonal violence, represented by healed cranial depressed fractures in 25 individuals of the sample of 93 crania analyzed in an on-going study (88). The morphology of the lesions suggests that these injuries were caused by blows to the head involving hard, round objects. A comparison of these data with archaeological findings from the site suggests that scores of hardened clay balls recovered from house and other contexts may have been the weapon of choice. Clay balls are especially well suited for sling propulsion, and their size and shape would fit the general morphology of the cranial injuries observed in the Çatalhöyük victims (88).

The demographic distribution of the injuries is highly patterned. Slightly more females than males are affected overall (13 vs. 10, respectively, for crania with a clear sex identification). Twelve of the 93 (13%) were injury recidivists, having sustained anywhere from 2 to 5 injuries over a span of time. Those with some of the highest recurrent injuries are adult females. For those victims, trauma predominates on the superior and posterior surfaces of their cranial vaults, suggesting that those women affected by interpersonal violence were not facing their assailants when struck. Chronologically, frequencies of cranial injuries are in line with the hypothesis of an increase in interpersonal violence during the Middle Period due to the changes in population size and density. An argument can be made for elevated stress and conflict within the community. This finding matches those from a number of settings today and in the archaeological past (85), confirming the association between violence and demographic pressure. On the other hand, the high degree of variation in trauma frequencies documented in past and present communities living in crowded settings does not, by itself, explain the variation in cranial trauma at Çatalhöyük. However, the association between social circumstances and interpersonal violence is compelling, especially in the development of a behavioral reconstruction in a crowded community and one engaged in relatively high-intensity farming (83).

Conclusions

The highly contextualized study of human remains from Neolithic Çatalhöyük contributes to an emerging picture of fundamental transitions in early complex societies during the Early Holocene, especially for those communities that adopted farming. The shift from a lifeway based exclusively on hunted, gathered, or collected foods to a lifeway involving domesticated plants and animals is a blink of an eye in the relative timescale of the 6 to 7 million years of hominin evolution or even of our species, *H. sapiens*, in the last 200,000 y. However, domestication resulted in fundamental changes in diet, living conditions, and society in the thousand or so years of the life of this Neolithic community, which ultimately formed the social, behavioral, and population characteristics that would develop into the modern world. In concert with its rich biocultural, social, behavioral, and environmental contexts, the study of human remains from Çatalhöyük provides important clues to the development of exploitative strategies during the Neolithic in the Near East and elsewhere, and changes in health, well-being, lifestyle, and behavior that contribute to the modern world. Importantly, the findings from Çatalhöyük permit an alternative perspective from which to consider the health challenges characterizing many communities today where overdependence on a limited range of foods (especially carbohydrates), elevated exposure to pathogens, the origin and rapid evolution of new pathogens, and unprecedented population expansion cause reductions in health and increases in mortality. The detailed context of Çatalhöyük and the integrative research focus applied to this site provide the opportunity to test hypotheses and to draw inferences about the biological, social, cultural, and behavioral adjustments to sedentism in modern humans and reliance on domesticated resources, health, and lifestyle (Table 1). The Çatalhöyük temporal variation discussed here shows adaptations and costs of increased population, sedentism, and crowding—factors that promote growth arrest, elevated infection, and compromised development. The pattern is consistent with global behavioral adaptations and nutritional compromises in the foraging-to-farming transition and farming intensification, namely, an adaptive system that promoted

fertility and population growth, while at the same time contributing to reduced quality of living circumstances and their outcome in health and well-being.

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1. M. N. Cohen, G. J. Armelagos, Eds., *Paleopathology at the Origins of Agriculture* (Academic Press, Orlando, FL, 1984).
2. C. S. Larsen, Biological changes in human populations with agriculture. *Annu. Rev. Anthropol.* **24**, 185–213 (1995).
3. T. D. Price, O. Bar-Yosef, The origins of agriculture: New data, new ideas. *Curr. Anthropol.* **52** (suppl. 2), S163–S164 (2011).
4. M. A. Zeder, The origins of agriculture in the Near East. *Curr. Anthropol.* **52** (suppl. 4), S221–S235 (2011).
5. C. S. Larsen, The agricultural revolution as environmental catastrophe: Implications for health and lifestyle in the Holocene. *Quat. Int.* **150**, 12–20 (2006).
6. C. S. Larsen, "Life conditions and health in early farmers: A global perspective on costs and consequences of a fundamental transition" in *Early Farmers: The View from Archaeology and Science*, A. Whittle, P. Bickle, Eds. (Oxford University Press, Oxford, UK, 2014), pp. 215–232.
7. R. H. Steckel, J. C. Rose, Eds., *The Backbone of History: Long-Term Trends in Health and Nutrition in the Americas* (Cambridge University Press, New York, NY, 2002).
8. H. Pringle, The slow birth of agriculture. *Science* **282**, 1446–1450 (1998).
9. D. Q. Fuller *et al*., Convergent evolution and parallelism in plant domestication revealed by an expanding archaeological record. *Proc. Natl. Acad. Sci. U.S.A.* **111**, 6147–6152 (2014).
10. S. N. DeWitte, Archaeological evidence of epidemics can inform future epidemics. *Annu. Rev. Anthropol.* **45**, 63–77 (2016).
11. C. S. Larsen,. The bioarchaeology of health crisis: Infectious disease in the past. *Annu. Rev. Anthropol.* **47**, 295–313 (2018).
12. A. Arranz-Otaegui, S. Colledge, L. Zapata, L. C. Teira-Mayolini, J. J. Ibáñez, Regional diversity on the timing for the initial appearance of cereal cultivation and domestication in southwest Asia. *Proc. Natl. Acad. Sci. U.S.A.* **113**, 14001–14006 (2016).
13. G. Willcox, "The beginnings of cereal cultivation and domestication in Southwest Asia" in *A Companion to the Archaeology of the Ancient Near East*, D. T. Potts, Ed. (Blackwell, Chichester, UK, 2012), pp. 163–180.
14. G. Willcox, Anthropology. The roots of cultivation in Southwestern Asia. *Science* **341**, 39–40 (2013).
15. D. Baird *et al*., Agricultural origins on the Anatolian plateau. *Proc. Natl. Acad. Sci. U.S.A.* **115**, E3077–E3086 (2018).
16. A. Whittle, P. Bickle, Eds., *Early Farmers: The View from Archaeology and Science* (Oxford University Press, Oxford, UK, 2014).
17. R. Pinhasi, J. T. Stock, Eds., *Human Bioarchaeology of the Transition to Agriculture* (Wiley-Blackwell, Chichester, UK, 2011).
18. C. B. Ruff *et al*., Gradual decline in mobility with the adoption of food production in Europe. *Proc. Natl. Acad. Sci. U.S.A.* **112**, 7147–7152 (2015).
19. A. Bayliss *et al*., Getting to the bottom of it all: A Baysesian approach to dating the start of Çatalhöyük. *J. World Prehist.* **28**, 27–68 (2015).
20. C. S. Larsen *et al*., Bioarchaeology of Neolithic Çatalhöyük: Lives and lifestyles of an early farming society in transition. *J. World Prehist.* **28**, 27–68 (2015).
21. J. L. Angel, Early Neolithic skeletons from Çatal Hüyük: Demography and pathology. *Anatol. Stud.* **21**, 77–98 (1971).
22. A. Czeszewska, "Wall paintings at Çatalhöyük" in *Integrating Çatalhöyük: Themes from the 2000-2008 Seasons*, I. Hodder, Ed. (Cotsen Institute of Archaeology, Los Angeles, CA, 2014), pp. 185–196.
23. J. Mellaart, *Çatal Hüyük: A Neolithic Town in Anatolia* (McGraw-Hill, New York, NY, 1967).
24. I. Hodder, Çatalhöyük: The leopard changes its spots. A summary of recent work. *Anatol. Stud.* **64**, 1–22 (2014).
25. S. D. Haddow, J. W. Sadvari, C. J. Knüsel, R. Hadad, "A tale of two platforms: Commingled remains and the life-course of houses at Neolithic Çatalhöyük" in *Theoretical Approaches to Analysis and Interpretation of Commingled Human Remains* (Springer, New York, NY, 2015), pp. 5–29.
26. S. D. Haddow, C. J. Knüsel, Skull retrieval and secondary burial practices in the Neolithic Near East: Recent insights from Çatalhöyük, Turkey. *Bioarchaeol. Int.* **1**, 52–71 (2017).
27. C. Cessford, "Estimating the Neolithic population of Çatalhöyük" in *Inhabiting Çatalhöyük: Reports from the 1995-99 Seasons*, I. Hodder, Ed. (McDonald Institute for Archaeological Research, Cambridge, UK, 2005), pp. 323–328.
28. B. S. Düring, Social dimensions in the architecture of Neolithic Çatalhöyük. *Anatol. Stud.* **51**, 1–18 (2001).
29. N. R. Russell *et al*., "Bringing down the house: House closing deposits at Çatalhöyük" in *Integrating Çatalhöyük: Themes from the 2000-2008 Seasons*, I. Hodder, Ed. (Cotsen Institute of Archaeology, Los Angeles, CA, 2014), pp. 109–121.
30. C. S. Larsen, *Bioarchaeology: Interpreting Behavior from the Human Skeleton* (Cambridge University Press, Cambridge, UK, ed. 2, 2015).
31. S. W. Hillson *et al*., "The human remains I: Interpreting community structure, health and diet in Neolithic Çatalhöyük" in *Humans and Landscapes of Çatalhöyük*, I. Hodder, Ed. (Cotsen Institute of Archaeology Press, Los Angeles, CA, 2013), pp. 339–396.
32. M. Milella, B. J. Betz, C. J. Knüsel, C. S. Larsen, I. Dori, Population density and developmental stress in the Neolithic: A diachronic study of dental fluctuating asymmetry at Çatalhöyük (Turkey, 7,100-5,950 BC). *Am. J. Phys. Anthropol.* **167**, 737–749 (2018).
33. D. Orton, J. Anvari, C. Gibson, J. Last, A tale of two tells: Dating the Çatalhöyük West Mound. *Antiquity* **92**, 620–639 (2018).
34. J. L. Brook, *Climate Change and the Course of Global History: A Rough Journey* (Cambridge University Press, New York, NY, 2014).
35. M. Roffet-Salque *et al*., Evidence for the impact of the 8.2-kyBP climate event on Near Eastern early farmers. *Proc. Natl. Acad. Sci. U.S.A.* **115**, 8705–8709 (2018).
36. G. Ayala *et al*., Palaeoenvironmental reconstruction of the alluvial landscape of Neolithic Çatalhöyük, central southern Turkey: The implications for early agriculture and responses to environmental change. *J. Archaeol. Sci.* **87**, 30–43 (2017).
37. M. Z. Barański, A. García-Suárez, A. Klimowicz, S. Love, K. Pawłowska, "The architecture of Neolithic Çatalhöyük as a process" in *Assembling Çatalhöyük*, I. Hodder, A. Marciniak, Eds. (European Association of Archaeology and Maney Publishing, Leeds, UK, 2015), pp. 111–126.
38. W. Matthews, C. French, T. Lawrence, D. Cutler, "Multiple surfaces: The micromorphology" in *On the Surface: Çatalhöyük 1993-95*, I. Hodder, Ed. (MacDonald Institute for Archaeological Research, Cambridge, UK, 1996), pp. 301–342.
39. W. Matthews, "Micromorphological and microstratigraphic traces of uses and concept of space" in *Inhabiting Çatalhöyük: Reports from the 1995-1999 Seasons*, I. Hodder, Ed. (MacDonald Institute for Archaeological Research, Cambridge, UK, 2005), pp. 355–398.
40. L.-M. Shillito *et al*., Biomolecular and micromorphological analysis of suspected faecal deposits at Neolithic Çatalhöyük, Turkey. *J. Archaeol. Sci.* **38**, 1868–1877 (2011).
41. L. M. Shillito *et al*., "Integrated geochemical and microscopic analysis of human coprolites, animal dung and organic remains in burials" in *Humans and Landscapes of Çatalhöyük: Reports of the 2000-2008 Seasons*, I. Hodder, Ed. (Cotsen Institute of Archaeology Press, Los Angeles, CA, 2013), pp. 77–91.
42. P. Moro, P. M. Schantz, Echinococcosis: A review. *Int. J. Infect. Dis.* **13**, 125–133 (2009).
43. A. Bogaard *et al*., "The archaeobotany of mid-later occupation levels at Neolithic Çatalhöyük" in *Humans and Landscapes of Çatalhöyük: Reports from the 2000-2008 Seasons*, I. Hodder, Ed. (Cotsen Institute of Archaeology Press, Los Angeles, CA, 2013), **vol. 8**, pp. 93–128.
44. A. Bogaard *et al*., Agricultural innovation and resilience in a long-lived early farming community: The 1,500-year sequence at Neolithic Çatalhöyük, central Anatolia. *Anatol. Stud.* **67**, 1–28 (2017).
45. M. Charles *et al*., "Landscape and taskscape at Çatalhöyük: An integrative perspective" in *Integrating Çatalhöyük: Themes from the 2000-2008 Seasons*, I. Hodder, Ed. (Cotsen Institute of Archaeology Press, Los Angeles, CA, 2014), pp. 71–108.
46. L. González Carretero, M. Wollstonecroft, D. Q. Fuller, A methodological approach to the study of archaeological cereal meals: A case study at Çatalhöyük East (Turkey). *Veg. Hist. Archaeobot.* **26**, 415–432 (2017).
47. N. Russell, K. Twiss, D. C. Orton, G. A. Demirjian, "More on the Çatalhöyük mammal remains" in *Humans and Landscapes of Çatalhöyük: Reports from the 2000-2008 Seasons*, I. Hodder Ed. (Cotsen Institute of Archaeology Press, Los Angeles, CA, 2013), **vol. 8**, pp. 213–258.
48. J. W. Sadvari *et al*., "The people and their landscape(s): Changing mobility patterns at Neolithic Çatalhöyük" in *Assembling Çatalhöyük. I*, I. Hodder, A. Marciniak, Eds. (European Association of Archaeologists, Maney Publishing, Leeds, UK, 2015), pp. 167–177.
49. N. Russell, L. Martin, "The Çatalhöyük mammal remains" in *Inhabiting Çatalhöyük: Reports from the 1995-1999 Seasons*, I. Hodder, Ed. (McDonald Institute for Archaeological Research, Cambridge, UK, 2005), pp. 33–98.
50. E. Henton, "Oxygen stable isotope and dental microwear evidence of herding practices at Çatalhöyük" in *Humans and Landscapes of Çatalhöyük: Reports from the 2000-2008 Seasons*, I. Hodder, Ed. (Cotsen Institute of Archaeology Press, Los Angeles, CA, 2013), pp. 299–316.
51. J. Pearson, "Human and animal diet as evidenced by stable carbon and nitrogen isotope analysis" in *Humans and Landscapes of Çatalhöyük: Reports from the 2000-2008 Seasons*, I. Hodder, Ed. (Cotsen Institute of Archaeology Press, Los Angeles, CA, 2013), pp. 271–298.
52. J. A. Pearson *et al*., New light on early caprine herding strategies from isotope analysis: A case study from Neolithic Anatolia. *J. Archaeol. Sci.* **34**, 2170–2179 (2007).

53. A. Bogaard *et al*., Locating land use at Neolithic Çatalhöyük, Turkey: The implications of $^{87}Sr/^{86}Sr$ signatures in plants and sheep tooth sequences. *Archaeometry* **56**, 860–877 (2014).
54. E. Asouti, "Woodland vegetation, firewood management and woodcrafts at Neolithic Çatalhöyük" in *Humans and Landscapes of Çatalhöyük: Reports from the 2000-2008 Seasons*, I. Hodder, Ed. (Cotsen Institute of Archaeology Press, Los Angeles, CA, 2013), pp. 129–162.
55. C. Doherty, *Sourcing Çatalhöyük Clays. Substantive Technologies at Çatalhöyük: Reports from the 2000-2008 Seasons* (Cotsen Institute for Archaeology, Los Angeles, CA, 2013), pp. 51–66.
56. J. A. Pearson *et al*., Stable carbon and nitrogen isotope analysis at Neolithic Çatalhöyük: Evidence for human and animal diet and their relationship to households. *J. Archaeol. Sci.* **57**, 69–79 (2015).
57. J. A. Pearson *et al*., Stable carbon and nitrogen analysis and dietary reconstruction through the life course at Neolithic Çatalhöyük, Turkey. *J. Soc. Archaeol.* **15**, 210–232 (2016).
58. M. A. Pilloud, C. S. Larsen, "Official" and "practical" kin: Inferring social and community structure from dental phenotype at Neolithic Çatalhöyük, Turkey. *Am. J. Phys. Anthropol.* **145**, 519–530 (2011).
59. P. Bourdieu, *Outline of a Theory of Practice* (Cambridge University Press, Cambridge, UK, 1977).
60. M. A. Pilloud *et al*., Mobility in Neolithic central Anatolia: A comparison of dental morphometrics and aDNA. *Am. J. Phys. Anthropol.* **162** (suppl. 64), 316 (2017).
61. L. W. Konigsberg, Migration models of prehistoric postmarital residence. *Am. J. Phys. Anthropol.* **77**, 471–482 (1988).
62. R. Huiskes, On the modelling of long bones in structural analyses. *J. Biomech.* **15**, 65–69 (1982).
63. C. B. Ruff, "Biomechanical analysis of archaeological human skeletons" in *Biological Anthropology of the Human Skeleton*, A. M. Katzenberg, A. L. Grauer, Eds. (Wiley, Hoboken, NJ, ed. 3, 2019), pp. 189–224.
64. C. B. Ruff, Ed., *Skeletal Variation and Adaptation in Europeans: Upper Paleolithic to the Twentieth Century* (Wiley, Hoboken, NJ, 2018).
65. E. M. Garofalo, C. B. Ruff, C. S. Larsen, Mobility at Neolithic Çatalhöyük: Temporal and ontogenetic contexts. *Am. J. Phys. Anthropol.* **162** (suppl. 64), 190 (2017).
66. E. M. Garofalo, C. B. Ruff, C. S. Larsen, Mobility and body size at Neolithic Çatalhöyük: Temporal patterns of a large-scale farming community in Turkey. *Am. J. Phys. Anthropol.* **165** (suppl. 66), 95 (2018).
67. A. Fairbairn, A history of agricultural production at Neolithic Çatalhöyük East, Turkey. *World Archaeol.* **37**, 197–210 (2005).
68. R. H. Steckel, C. S. Larsen, C. A. Roberts, J. Baten, Eds., *The Backbone of Europe: Health, Diet, Work, and Violence over Two Millennia* (Cambridge University Press, Cambridge, UK, 2019).
69. B. Bogin, *The Growth of Humanity* (Wiley, New York, NY, 2001).
70. S. Stinson, "Growth variation: Biological and cultural factors" in *Human Biology: An Evolutionary and Biocultural Perspective*, S. Stinson, B. Bogin, D. O'Rourke, Eds. (Wiley, Hoboken, NJ, 2012), pp. 425–463.
71. V. B. DeLeon, Fluctuating asymmetry and stress in a medieval Nubian population. *Am. J. Phys. Anthropol.* **132**, 520–534 (2007).
72. J. T. Richtsmeier, T. M. Cole, S. R. Lele, "An invariant approach to the study of fluctuating asymmetry: Developmental instability in a mouse model for Down syndrome" in *Modern Morphometrics in Physical Anthropology*, D. E. Slice, Ed. (Kluwer Academic, New York, NY, 2005), pp. 187–212.
73. L. Van Valen, A study of fluctuating asymmetry. *Evolution* **16**, 125–142 (1962).
74. E. Bocaege, "Childhood growth in the Neolithic: A detailed study of Çatalhöyük," PhD thesis, University College London, London, UK (2015).
75. C. B. Ruff, E. Garofalo, M. A. Holmes, Interpreting skeletal growth in the past from a functional and physiological perspective. *Am. J. Phys. Anthropol.* **150**, 29–37 (2013).
76. D. A. Weston, "Nonspecific infection in paleopathology: Interpreting periosteal reactions" in *A Companion to Paleopathology*, A. Grauer, Ed. (Wiley-Blackwell, Chichester, UK, 2012), pp. 492–512.
77. C. Marques, V. Matos, N. J. Meinzer, "Proliferative periosteal reactions: Assessment of trends in Europe over the past two millennia" in *The Backbone of Europe: Health, Diet, Work, and Violence over Two Millennia*, R. H. Steckel, C. S. Larsen, C. A. Roberts, J. Baten, Eds. (Cambridge University Press, Cambridge, UK, 2019), pp. 137–174.
78. C. J. Houldcroft, J.-B. Ramond, R. F. Rifkin, S. J. Underdown, Migrating microbes: What pathogens can tell us about population movements and human evolution. *Ann. Hum. Biol.* **44**, 397–407 (2017).
79. C. Roberts, K. Manchester, *The Archaeology of Disease* (Sutton Publishing, Stroud, UK, ed. 3, 2005).
80. K. Harper, G. Armelagos, The changing disease-scape in the third epidemiological transition. *Int. J. Environ. Res. Public Health* **7**, 675–697 (2010).
81. I. Dori, M. Milella, J. W. Sadvari, C. S. Larsen, C. J. Knüsel, The various faces of prehistoric "well-being": The relative effects of sex, age, and population density on dental pathological condition at Neolithic Çatalhöyük (Central Anatolia, Turkey). *Am. J. Phys. Anthropol.* **165** (suppl. 66), 71 (2018).
82. C. Knüsel, M. J. Smith, Eds., *The Routledge Handbook of the Bioarchaeology of Human Conflict* (Routledge, London, UK, 2014).
83. P. M. Lambert, M. H. Welker, Traumatic injury risk and agricultural transitions: A view from the American Southeast and beyond. *Am. J. Phys. Anthropol.* **162**, 120–142 (2017).
84. R. Schulting, L. Fibiger, Eds., *Sticks, Stones, and Broken Bones: Neolithic Violence in a European Perspective* (Oxford University Press, Oxford, UK, 2012).
85. P. L. Walker, A bioarchaeological perspective on the history of violence. *Annu. Rev. Anthropol.* **30**, 573–596 (2001).
86. Y. S. Erdal, Ö. D. Erdal, Organized violence in Anatolia: A retrospective research on the injuries from the Neolithic to Early Bronze Age. *Int. J. Paleopathol.* **2**, 78–92 (2012).
87. B. Glencross, B. Boz, "Representing violence in Anatolia and the Near East during the transition to agricuilture" in *The Routledge Handbook of the Bioarchaeology of Human Conflict*, C. Knüsel, M. J. Smith, Eds. (Routledge, London, UK, 2014), pp. 90–108.
88. C. J. Knüsel, B. Glencross, Çatalhöyük, archaeology, violence. *Contagion J. Violence Mimesis Culture* **24**, 23–36 (2017).
89. D. Ferembach, Les hommes du gisement néolithique de Çatal Hüyük. *Türk Tarih Kongresi* **7**, 13–21 (1972).
90. T. Molleson, J. Ottevanger, T. Compton, Variation in Neolithic teeth from Çatalhöyük (1961-1964). *Anatol. Stud.* **54**, 1–26 (2004).
91. T. Molleson, P. Andrews, B. Boz, "Reconstruction of the Neolithic people at Çatalhöyük" in *Inhabiting Çatalhöyük: Reports from the 1995-99 Seasons*, I. Hodder, Ed. (McDonald Institute for Archaeological Research, Cambridge, UK, 2005), pp. 279–300.
92. T. Molleson, "Times of stress at Çatalhöyük" in *Faces from the Past: Diachronic Patterns in the Biology of Human Populations from the Eastern Mediterranean*, M. Faerman, L. K. Horwitz, T. Kahana, U. Zilberman, Eds. (British Archaeological Reports, 2007), no. 1603 pp. 140–150.