Journal of Interdisciplinary History, xxxvi:1 (Summer, 2005), 1–32.

Richard H. Steckel

Health and Nutrition in Pre-Columbian America: The Skeletal Evidence In his presidential address to the American Historical Association, Coatsworth argued that study of change over time in physical or spiritual well-being is the central unifying concern of history. Although one may quibble with the generalization, any reasonable time and motion study would find that historians devote most of their research efforts to gathering, organizing, interpreting, and disseminating information about human welfare or the quality of life broadly defined.[1]

Human welfare is conceptually complex and difficult to measure, even today. Accurate measurement of inflation is a case in point. Assuming that the consumer price index overstates the increase in the true cost of living by as little as one percentage point per year (as many economists have argued), the cumulative addition to the national debt from overindexing the federal budget is more than $1 trillion in just twelve years. The error also substantially affects the measurement of poverty and of real median income in the quarter-century after 1973. If such an issue about a modest slice of physical well-being cannot be resolved without argument, it is little wonder that debates are intense about the distant past, when written evidence is thin, and surveys collected by government and private efforts are unavailable.[2]

Under these conditions, the less venturesome may throw up their hands and avoid research areas lacking familiar types of written information, but to do so is unsatisfactory as a general rule. Sometimes we should face the risks and make the effort to cross traditional disciplinary boundaries in search of new evidence,

Richard H. Steckel is SBS Distinguished Professor of Economics, Anthropology, and History, Ohio State University. He is co-editor, with Jerome C. Rose, of *The Backbone of History: Health and Nutrition in the Western Hemisphere* (New York, 2002); co-author, with Joseph H. Prince, of "Nutritional Success on the Great Plains: Nineteenth-Century Equestrian Nomads," *Journal of Interdisciplinary History,* XXXIII (2003), 353–384.

1 John H. Coatsworth, "Welfare," *American Historical Review,* CI (1996), 1–12.
2 Michael J. Boskin et al., "Consumer Prices, the Consumer Price Index, and the Cost of Living," *Journal of Economic Perspectives,* XII (1998), 3–26.

especially if it enlightens opinion on intriguing topics that are meager in standard sources.

This article makes such a journey, bringing substantial new evidence to bear on a topic characterized by an unusually high ratio of debate to factual information—physical well-being in pre-Columbian America. The new data measure health as seen from the skeletal remains of more than 4,000 individuals who lived in North, Central, or South America in the millennia before 1492. Because skeletons are an unfamiliar source to most social scientists, a methodology section allows the paper to be moderately self-contained. A novel procedure for condensing diverse skeletal data into a single measure of health is also described. The results have implications for understanding the environmental determinants of health, the pre-Columbian disease environment, plausible ranges of pre-contact population size, and the pattern of European conquest.

BACKGROUND Economists have contributed, but archaeologists, physical anthropologists, and historians have published the bulk of the academic research about pre-Columbian America. Archaeological information, such as material artifacts or the number and character of Native American settlements, is often cited by historians, but bioarchaeological evidence (skeletons that indicate kinds and degrees of biological stress) are essentially unknown in the historical literature.[3]

A thorough explanation for this lacuna is beyond the scope of this study, but some observations are relevant. Paleopathology, or the study of human health and disease from skeletal remains, is a relatively new field, emerging among specialists only in the middle

3 Much research in the disciplines is defined, or at least significantly constrained, by materials and methods, as opposed to organization based on the broader subject matter or research problem. The history of Native Americans, as investigated by historians as well as scholars from other fields, emphasizes written records and therefore the period since the late 1400s. This literature gives great attention to population size at contact and the demographic aftermath of European exploration and colonization. Some examples are David P. Henige, *Numbers from Nowhere: The American Indian Contact Population Debate* (Norman, 1998); Noble David Cook, *Born to Die: Disease and New World Conquest, 1492–1650* (New York, 1998); Russell Thornton, "Population History of Native North Americans," in Michael R. Haines and Steckel (eds.), *A Population History of North America* (New York, 2000), 9–50; *idem, American Indian Holocaust and Survival: A Population History since 1492* (Norman, 1990); William M. Denevan, *The Native Population of the Americas in 1492* (Madison, 1992); Alfred W. Crosby, *The Columbia Exchange: Biological and Cultural Consequences of 1492* (Westport, Conn., 2003).

of the twentieth century. It has yet to spread more widely in the social sciences. The technical nature and focus of the subject are obstacles to diffusion; as graduate students, physical anthropologists are trained in anatomy and skeletal biology, which are typically beyond the interests or reach of other social scientists. Moreover, physical anthropologists often think like medical professionals, wanting to discover purely biological processes that create pathological lesions or to diagnose ailments of individuals long dead. They usually lack the broad perspective of social scientists interested in larger environmental processes that shape community health, much less long-term historical forces that affect the rise or fall of civilizations.

Typically, physical anthropologists are too poorly equipped, or otherwise constrained, to convince historians of the importance and relevance of their evidence. Their research projects are labor-intensive, involving travel, difficult lodging (sometimes in tents); many hours of excavation to recover a single burial; plus cleaning, coding, and analysis of skeletons and other artifacts. The study of one, or at most a few small geographical sites often occupies an entire career. In short, physical anthropologists not only have little training but also little time and data to incline them toward a broad comparative perspective.

The field is also burdened by its distant past. Social scientists mildly acquainted with physical anthropology often connect it with racism, phrenology, or other forms of discredited pseudo-scientific research. This mental association is decaying over time as new generations are trained, but memories linger. Most social scientists still must be persuaded that the subject is useful. This situation has some parallels with the challenges faced by anthropometric history in the 1970s, which prospered only after this new field explained its methodology in terms intelligible to social scientists and successfully addressed several historical questions which already had garnered established interest.[4]

This article vastly extends the reach of anthropometric history by expanding the information base to skeletons, which depict important aspects of well-being over millennia and embrace human activities from hunting/gathering to settled agriculture, the rise of

4 Jonathan Marks, *Human Biodiversity: Genes, Race, and History* (New York, 1995); Steckel, "Strategic Ideas in the Rise of the New Anthropometric History and Their Implications for Interdisciplinary Research," *Journal of Economic History,* LVIII (1998), 803–821.

cities, global exploration and colonization, and eventual industrialization. Skeletons are widely available for study in many parts of the globe, and unlike heights, they depict health over a life cycle. As a package, skeletal measures provide age and source-specific detail on biological stress from early childhood through old age—not only for men but also for women and children, two groups often excluded from more familiar historical sources, such as tax documents, muster rolls, and wage records. Skeletons provide a more extensive and complete picture of community health than available from historical records on stature. They are most useful when combined with data from archaeology, historical documents, climate history, Geographic Information Systems (GIS), and other sources.

The results discussed herein expand upon a large collaborative project involving economists, historians, and physical anthropologists who have assembled numerous measures of skeletal health for individuals who once lived in the Western Hemisphere. Sampling issues inevitably arise in the comparative study of skeletons, as well as ambiguities in interpreting the biological evidence. Confidence in the approach is bolstered, however, by comparing results with patterns of health that are well established from other sources.[5]

MEASURES OF BIOLOGICAL STRESS Unlike dental enamel, bones are living tissues that receive blood and adapt to mechanical and physiological stress. Habitual physical activity that requires exertion leads to a readily visible expansion of the related muscle attachments on the skeleton. The building process, articulated over a century ago by Wolff, is rapid for growing children but also occurs among adults, albeit at a slower rate. If the action is repetitive in a particular direction, the bones adapt to the load by thickening in the direction of the plane of motion. Hunter-gatherers who walked long distances, for example, had oval-shaped femurs; these bones were nearly circular among settled agriculturalists that had diverse activity patterns. Similarly, professional athletes such as tennis players and baseball pitchers develop extensive muscles, tendons and bones in the shoulders and arms on the side that they habitually use.[6]

5 Steckel and Jerome C. Rose (eds.), *The Backbone of History: Health and Nutrition in the Western Hemisphere* (New York, 2002).

6 For discussion and references to the literature, see Tim D. White and Pieter A. Folkens, *Human Osteology* (San Diego, 2000); Alan S. Goodman and Debra L. Martin, "Recon-

Net nutrition has been a useful concept for understanding the environmental factors that influence human growth. The body is a biological machine that requires fuel for basal metabolism, to perform work, and to combat infection, all of which claim dietary intake. If net nutrition is insufficient, child growth slows or ceases. Deprivation that is chronic and severe stunts linear growth of a skeleton. More generally, a skeleton is an incomplete but useful repository of an individual's history of biological stress, as explained below.[7]

In principle, anthropologists could use any bone to estimate stature, but the femur, which comprises about one-quarter of standing height, and is often well preserved and easily measured, has the greatest correlation with stature. The classic study estimated the relationship between the two variables using femur lengths of deceased people whose living height was known from muster rolls or other sources. The equations vary somewhat by sex (females are a few centimeters shorter than males for a given femur length), and accurate height estimates require anthropologists to draw upon sexually dimorphic characteristics of the pelvis and the skull that appear in adolescence. Growth plates obfuscate the bone lengths of juveniles, and height estimates are correspondingly problematical until the bony components of the femur fuse late in the teenage years.[8]

As a group, physical anthropologists collect hundreds of skeletal measures, many of which are specialized and some of which reflect rare or unusual forms of physiological stress. Large collaborative studies of community health are well advised to concentrate on general health indicators that are understood and reported by virtually all physical anthropologists, regardless of specialty. In one such study that investigated skeletal health during the past several

structing Health Profiles from Skeletal Remains," in Steckel and Rose (eds.), *Backbone of History,* 11–60. Wolff was a nineteenth-century surgeon who formulated what skeletal biologists call Wolff's Law, which is the principle that mechanical stress determines the architecture of bone: "Remodeling of bone . . . occurs in response to physical stresses—or the lack of them—in that bone is deposited in sites subjected to stress and is resorbed from sites where there is little stress" (quoted from Robert Bruce Salter, *Textbook of Disorders and Injuries of the Musculoskeletal System: An Introduction to Orthopaedics, Rheumatology, Metabolic Bone Disease, Rehabilitation and Fractures* [Baltimore, 1970], 7).

7 See James M. Tanner, *Foetus into Man: Physical Growth from Conception to Maturity* (Cambridge, Mass., 1978); Steckel, "Stature and the Standard of Living," *Journal of Economic Literature,* XXXIII (1995), 1903–1940.

8 Mildred Trotter and Goldine C. Gleser, "Estimation of Stature from Long Bones of American Whites and Negroes," *American Journal of Physical Anthropology,* X (1952), 463–514.

thousand years, the evidence included three indicators of health during childhood (stature, linear enamel defects, and skeletal signs of anemia), two measures of decline among adults (dental decay and degenerative joint disease), and two that could affect any age group but tend to be more prevalent among older children and adults (skeletal infections and trauma). Stature has already been discussed as a child health indicator; the others are briefly explained below.[9]

Enamel Hypoplasias (Linear Enamel Defects) Hypoplasias are readily visible lines or pits of enamel deficiency commonly found in the teeth (especially incisors and canines) of people whose early childhood was biologically stressful. They are caused by disruption to the cells (ameloblasts) that form the enamel, usually due to environmental factors like poor nutrition and/or infectious disease. Although nonspecific, hypoplasias are informative about childhood physiological stress in archaeological settings.

Indicators of Iron Deficiency Anemia (Porotic Hyperostosis and Cribra Orbitalia) Iron is essential for many body functions, such as oxygen transport to the body's tissues. When iron is deficient—owing to nutritional deprivation, low body weight, chronic diarrhea, parasite infection, and other factors—the body attempts to compensate by increasing red blood-cell production. The manifestations are easily visible in the skeletons of young children in areas where red blood-cell production occurs, such as the flat bones of the cranium. The associated pathological conditions are sieve-like lesions called porotic hyperostosis and cribra orbitalia for the cranial vault and eye orbits, respectively. These lesions can have many causes, but iron deficiency is among the most common. In infancy and childhood, iron-deficiency anemia is associated with impaired growth and delays in behavioral and cognitive development. In adulthood, the condition is associated with limited work capacity.

Dental Health Dental health is an important indicator of both oral and general health, which is assessed in archaeological skeletons from dental caries, antemortem tooth loss, and abscesses.

9 For a discussion of variables, see Jane E. Buikstra and Douglas H. Ubelaker, *Standards for Data Collection from Human Skeletal Remains* (Fayetteville, Ark., 1994). For additional information on the meaning of variables, see text and references in Clark Spencer Larsen, *Bioarchaeology: Interpreting Behavior from the Human Skeleton* (New York, 1997); White and Folkens, *Human Osteology.*

Dental caries is a disease process characterized by the focal demineralization of dental hard tissues by organic acids produced by bacterial fermentation of dietary carbohydrates, especially sugars. In the modern era, the introduction and general availability of refined sugar caused a huge increase in dental decay. In the more distant past, the adoption of agriculture led to a general increase in tooth decay, especially after the introduction of maize. The agricultural shift and the later use of increasingly refined foods have resulted in an increase in periodontal disease, caries, tooth loss, and abscesses.

Degenerative Joint Disease Degenerative joint disease (DJD) is commonly caused by the mechanical wear and tear on the joints of the skeleton due to physical activity. Generally speaking, populations engaged in habitual activities that are physically demanding have more DJD (especially buildup of bond along joint margins and deterioration of bone on articular joint surfaces) than populations that are relatively sedentary. Studies of DJD have been valuable in documenting levels and patterns of activity in past populations.

Skeletal Infections (Osteoperiostitis) Skeletal lesions of infectious origin, which commonly appear on the major long bones, have been documented worldwide. Most of these lesions are plaque-like deposits from inflammation of the periosteum, which is a vascular connective tissue with born-forming capability that lines all bone surfaces (except joints). Substantial inflammation for months or years creates swollen bone shafts and irregular elevations on bone surfaces. The lesions are often caused by *Staphylococcus* or *Streptococcus* bacteria that penetrate to the periosteum following injuries. Although these lesions can appear on any bone, the front of the tibia (shin) is especially vulnerable, since this section of bone often suffers minor injuries and has little muscle or other soft tissue to protect the periosteum. These lesions have proven informative about patterns and levels of community morbidity, because the infections fester and progress if the immune system is weakened by poor net nutrition.

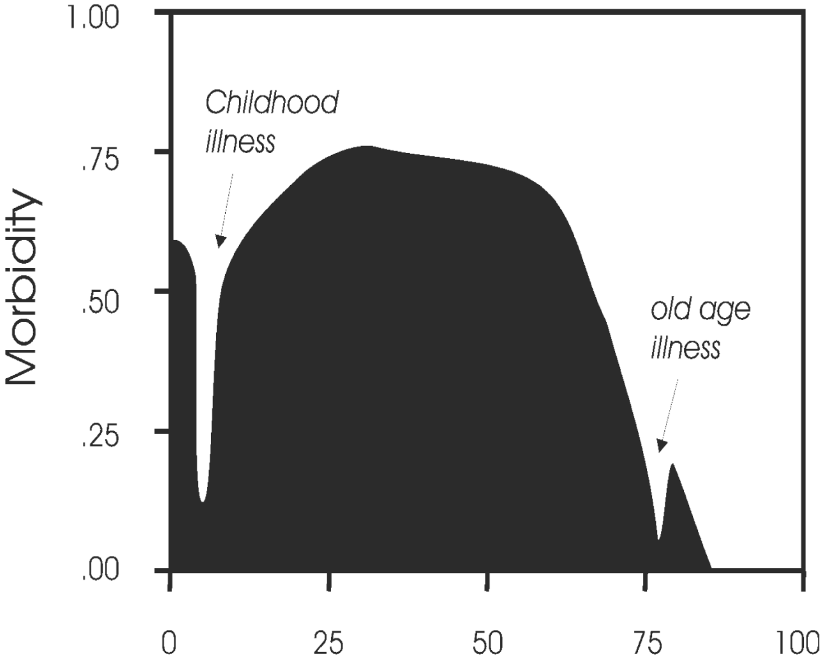
Trauma Fractures, weapon wounds, and other severe injuries often create bone malformations that provide a record of accidents or violence. The visible record understates the actual level of trauma, however, because traumas do not always involve the skeleton, some bones realign well, and healing can hide many injuries, especially in children, who rapidly form new bone that can hide scars. In preindustrial societies that lacked x-rays, plaster casts, and other devices (such as pins or screws), the changes were slim, however, for bone alignment that did not leave visible scars. The pattern of scars differs for accidents versus deliberate trauma. Violence often registers on the top or back of the head, the face, or the back. Other forms include cut marks, bullet holes, and embedded arrow points. Accidental injuries, common as ankle, wrist, and forearm fractures, often reflect difficulty of terrain or the hazards of specific occupations. Deliberate skeletal trauma provides a barometer of domestic strife, social unrest, and warfare.

TWO DIMENSIONS OF HEALTH Demographers and medical professionals agree that length of life and morbidity are central elements of health. The methodology for measuring life expectancy at birth was refined during the nineteenth century, but much less agreement exists on principles for the second. Death is usually well defined, but morbidity is much less precise. The incidence of various chronic diseases, days lost from school or work, and assessments of physical capacity all have their value, but all have conceptual limitations. Moreover, gathering reasonably comprehensive and accurate morbidity information is often time-consuming and expensive. Significant progress on the problem may be made eventually by using devices that transmit information from receptors implanted in or on the body.

Figure 1 illustrates the principles involved in measuring health. The horizontal axis measures length of life and is conceptually straightforward. The vertical axis simplifies by compressing the diverse aspects of morbidity into a single number scaled from 0.0 (death, or total incapacitation) to 1.0 (complete absence of disability). Medical examinations could be used to rate individuals on the morbidity scale. In the example illustrated by Figure 1, a person who suffered a major illness in early childhood becomes substantially free of morbidity impediments until old age. Average life-time health can be measured by the shaded area under the curve, which is similar to the concept of quality-adjusted life years in the health economics literature. Community health can be tabulated as the average of quality-adjusted life years across individuals.[10]

10 George W. Torrance and David Feeny, "Utilities and Quality-Adjusted Life Years," *International Journal of Technology Assessment in Health Care,* V (1989), 559–575.

Fig. 1 Hypothetical Example of Morbidity by Age



How well do skeletons capture the two elements of health? At most localities or burial sites, an incomplete but useful picture is available for the vertical axis (morbidity), which can be adjusted for the age distribution of deaths, as discussed below for the health index. Life expectancy is more problematical. In a stationary population (one neither growing nor shrinking), life expectancy equals the average age at death, but confirming stationary conditions may be difficult from available archaeological or historical information. More generally, the average age at death is affected by the birth rate and by migration. A high birth rate, for example, creates a young age distribution and therefore relatively more deaths among children (infants and young children have high death rates), biasing the average age at death downward as a measure of life expectancy. The life table corrects for this problem by basing calculations on age-specific death rates (the ratio of deaths in an age group to the number of people in that age group), which unfortunately are unknown in most skeletal samples because the number of people who were alive at each age (the denominator) typically is unavailable. At a minimum, estimates of life expectancy are hazardous without good contextual information from archaeology and other sources, but even with it, reliable methods to estimate birth rates or migration rates from the available evidence may be lacking. This is an important frontier of research in paleodemography.

Yet, lack of information on life expectancy is less limiting than it might appear for the study of health. To the extent that morbidity and mortality are positively correlated, skeletal lesions provide enough information about life expectancy to permit health to be ranked across localities or time periods based on morbidity alone. Measuring the relationship between morbidity and mortality is critical for further research, but progress has been slow, in part because morbidity is difficult to measure consistently. Sickness rates among U.S. army troops stationed in the continental United States, however, were positively and substantially related to mortality during the first half of the twentieth century. Crude estimates of life expectancy obtained from skeletons in the Western Hemisphere project were inversely related to chronic morbidity across fifty localities. Although common sense might suggest that morbidity and mortality are positively related, the correlation might not be huge; the relationship between these two distinct aspects of health can be affected differently by technological and socioeconomic forces. Thus, skeletal lesions are useful but furnish an imperfect picture of health.[11]

Skeletons are good at summarizing several types of chronic morbidity, but not various soft-tissue conditions such as hernias or torn ligaments. Degenerative joint disease and dental decay often develop over many years, with adverse functional consequences. DJD is painful and limits mobility, whereas dental decay's effect on the ability to chew and digest a coarse diet impairs net nutrition, weakens the immune system, and increases vulnerability to illness. Skeletal signs of anemia (cribra orbitalia and porotic hyperostosis) usually appear early in childhood. The adverse environmental conditions that created these bony malformations tend to persist thereafter. Skeletal infections are often painful and signal a weak-

11 Suchit Arora, "The Relation of Sickness to Deaths: Evidence from the U.S. Army, 1905–39" (Columbus, 2002); Steckel and Rose, "Conclusions," in *idem* (eds.), *Backbone of History,* 583–589. For an alternative point of view on the relationship between sickness and life expectancy, see James C. Riley, *Sick, Not Dead: The Health of British Workingmen During the Mortality Decline* (Baltimore, 1997).

ened immune system that can lead to illness and functional loss. Broken bones and weapon wounds require time to heal, and the loss of mobility or dexterity associated with them can be permanent if they heal in a misaligned fashion.

Stunting and linear enamel hypoplasias (LEH) are not direct measures of morbidity, but they signal a loss of functional capacity. Serious hunger limits physical activity in the fashion of anemia; hypoplasias are usually the direct result of severe disease or malnutrition in early childhood. These skeletal lesions therefore index various types of morbidity.

SAMPLING ISSUES Physical anthropologists may have little control over the location and extent of excavations that result from a development project that clears a small plot of ground. With the exception of the removal of entire cemeteries containing reasonably closed populations, skeletons rarely represent an entire society. Many collections in Europe, for example, come disproportionately from cities and towns, where much construction has occurred relative to rural areas.

These constraints are a hindrance but far from disabling. The formulation of a large comparative project involving numerous sites can be stratified for representation from rural and urban areas. Post-weighting samples is a second option. As discussed below, research can sidestep age bias by converting information to age-specific rates, if the age distribution of deaths has been skewed by fertility, migration, or excavation.

COMMUNITY HEALTH Numerous simplifying assumptions and approximations are required to distill diverse skeletal data into a single number for comparative ranking and study of populations. Ideally, both life expectancy and morbidity would be available, permitting rough approximation of a measure such as quality-adjusted life years. For various reasons—for example, incomplete excavation of burials, migration, or unmeasured differences in fertility rates—however, many sites in a collaborative project lack reliable estimates of life expectancy. The health index discussed herein incorporates only morbidity as expressed in the frequency and severity of skeletal lesions, but the index could easily be adapted to incorporate length of life. But the likely positive correlation between morbidity and mortality mitigates the lack of data on life expectancy in ranking health. This formulation of the index underestimates the true variation in health (as measured by quality-adjusted life years) across sites.[12]

The index was estimated using the following sequence of steps:

(1) For each individual, the seven skeletal measures of morbidity discussed above were graded on a scale of 0 (most severe expression) to 100 (no lesion or deficiency). A higher score indicates better health.
(2) Age-specific rates of morbidity pertaining to the health indicators during childhood (stature, LEH, and anemia) were assumed to have persisted from birth to death, the justification being the knowledge that childhood deprivation negatively affects adult health. The duration of morbidity prior to death is in fact unknown for the remaining four components (infections, trauma, DJD, and dental decay), but these skeletal lesions clearly reflect chronic conditions that typically persist for several years. Although the durations are the subject of ongoing research, on a provisional basis they were assumed to have existed for ten years prior to death.[13]
(3) The age-specific rates for each of the seven attributes of the index were calculated as ratios in which the numerator equals the average grade or score at a particular age and the denominator equals the number of person-years of morbidity observed at that age. Results were grouped into age categories of 0–4, 5–9, 10–14, 15–24, 25–34, 35–44, and 45+.
(4) The age-specific rates for each attribute were weighted by the relative number of person-years lived in a reference population (Model West level 4) that is believed to agree roughly with pre-Columbian mortality conditions in the Western Hemisphere. The results were multiplied by life expectancy in this reference population and expressed as a percentage of

12 For additional details and justification concerning the methodology, see Steckel, Paul W. Sciulli, and Rose, "A Health Index from Skeletal Remains," in Steckel and Rose (eds.), *Backbone of History,* 61–93. Presumably, future research will help to develop the health index using more appropriate assumptions.

13 The effect of fetal and early childhood health on adult health is sometimes called the Barker hypothesis, which is discussed in David J. P. Barker, *Mothers, Babies, and Health in Later Life* (Edinburgh, 1998). For additional discussion, see Robert W. Fogel and Dora L. Costa, "A Theory of Technophysio Evolution, with Some Implications for Forecasting Population, Health Care Costs, and Pension Costs," *Demography,* XXXIV (1997), 49–66.

the maximum attainable, which corresponds to a complete lack of skeletal defects or lesions. This procedure effectively denudes the health index of true differences in life expectancy because all populations are assumed to have had the same age-specific death rates.[14]

(5) The seven components of the index were then weighted equally to obtain the overall index.

Numerous assumptions underlying the index can be challenged, modified, and refined, but this article is not the place to do so. Weighting the elements of the index, such as dental decay and trauma, by their functional consequences would be appropriate, but it is complicated by the nature of the social safety net, medical technology, and other factors that vary indeterminately across societies. Equal weighting may be questionable, but an alternative scheme given the present state of knowledge is also difficult to justify. Furthermore, the index is an additive measure that ignores interactions, but suffering both a skeletal infection and trauma, for example, could have been worse than the sum of their independent effects on health. The present state of knowledge does not permit interaction effects to be included.[15]

A TEST OF THE INDEX METHODOLOGY Comparing results with patterns well established in historical studies helps in assessing the health index as a work in progress. Settlement size is a suitable category, because a great deal is known about it from historical records. Prior to effective public-health measures near the end of the nineteenth century, urban areas were notoriously unhealthy. Large, permanent concentrations of people accumulated waste that harbored parasites detrimental to health. Close contact, often in crowded places of living or work, readily spread many diseases. In addition, cities usually had substantially unequal distributions of wealth and power. Large differences in access to resources and in

14 The Model West level 4 population has a life expectancy at birth of 26.4 years. For a discussion of model life tables, see Ansley J. Coale and Paul George Demeny, *Regional Model Life Tables and Stable Populations* (Princeton, 1966). Known differences in life expectancy could be incorporated easily into a modified index. Changing the life expectancy or model life table modifies the weights (relative number of person-years lived in each age group) but not the age-specific morbidity rates.

15 For a discussion of interaction effects in a modern context, see Torrance and Feeny, "Utilities and Quality-Adjusted Life Years."

work effort had important ramifications for health. Similar circumstances probably existed in the pre-Columbian world. Other things being equal, more mobile, less densely settled populations most likely were healthier than those living in towns or urban areas that served as centers of government administration.[16]

Because European expansion distorted Native American mortality patterns in ways that could have obscured the effects of settlement size, comparisons are limited to pre-Columbian sites, which include skeletons of 4,078 individuals who lived in twenty-three localities in North, Central, and South America. Steckel and Rose used archaeological evidence to arrange the settlements into three types: mobile populations (essentially hunter-gatherers), village or settled but dispersed populations, and town or paramount urban centers. The estimated regression of the health index on settlement type is

$$\begin{aligned} HI &= \underset{(3.04)}{78.98} - \underset{(3.47)}{8.71}\ \text{Village} - \underset{(3.92)}{14.91}\ \text{Urban}, \\ N &= 23,\ R^2 = 0.42, \end{aligned} \qquad (1)$$

where standard errors are given in parentheses, and the mean and standard deviation of the dependent variable are 70.5 and 8.0, respectively. The coefficients are both statistically and practically significant. The health index was nearly two standard deviations lower in the largest urban setting than in mobile groups.[17]

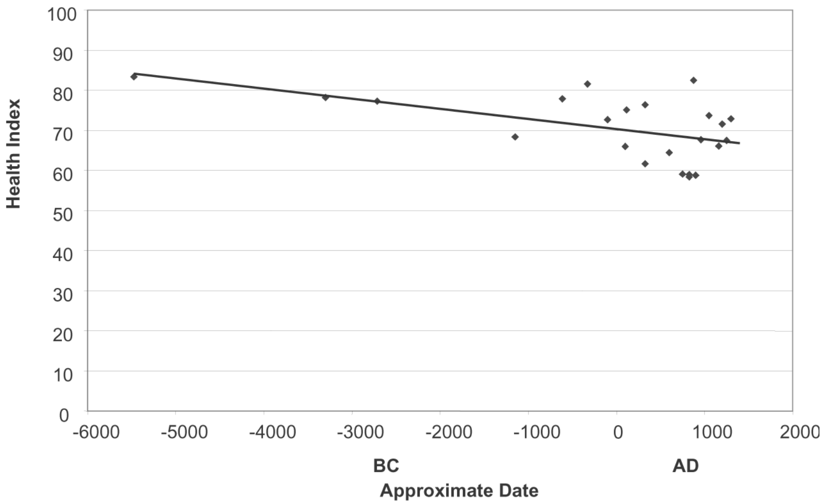
That the health index systematically declined with increasing settlement size is welcome news for the methodology. The index thus passed an important preliminary test, suggesting that it is credible even in its crude form. Presumably, refinements in the methodology will sharpen the quantification of important aspects of health.

LONG-TERM TREND An interesting pattern emerges from arranging the evidence by average age of the sites measured in years before present (YBP), the "present" being 1950. Figure 2 shows a scatter diagram of the health index at twenty-three pre-

16 Various types of sensitivity analysis and formulation of standard errors are also planned, following public reaction to the methodology of the health index.

17 Details about the sites are available from Steckel, Sciulli, and Rose, "A Health Index from Skeletal Remains"; Steckel and Rose, "Patterns of Health in the Western Hemisphere," in *idem* (eds.), *Backbone of History,* 563–579.

Fig. 2 Time Trend in Pre-Columbian Health



NOTE Deterioration in health is indicated by the downward trend of the linear regression line associated with these points ($R^2 - 0.28$; $p \leq 0.05$). The health index declined by an average of 2.5 points per millennium.
SOURCE Calculated from Western Hemisphere database.

Columbian sites where all seven attributes were reported by the different research teams. The downward trajectory is statistically significant in a simple linear regression:

$$\underset{(2.26)}{HI = 65.41} + \underset{(0.00087).}{0.0025\ YBP}, \quad N = 23, \quad R^2 = 0.28 \qquad (2)$$

Standard errors are shown in parentheses. Regrettably, few sites were located in the early pre-Columbian period—only three data points before approximately 1000 B.C., the scarcity complicating the interpretation of the time trend. This particular scattering of sites imparts a high standard deviation to the independent variable (time), which may well artificially shrink the standard error of the coefficient; that is, a few chronological outliers may heavily affect the estimated relationship. This chronological concentration makes it important to consider factors that may have contributed to variability in the index, regardless of time period. The goal is to determine whether measurable environmental effects can explain the downward trajectory in the health index.[18]

Other measurable variables collected for each site include food sources, vegetation, topography, elevation, and settlement pattern. Although the pathway of causation for each of these variables is impossible to specify in detail, we have a general sense of their possible mechanisms of operation. Food sources were obvious variables to consider because diet affects human growth and other aspects of health, such as resistance to infections. What may appear to be a simple relationship between diet and the health index, however, is made complex by interactions with other ecological variables like topography, climate, settlement size, and trade. Settled agriculture provided a greater supply of foods such as maize, beans, and squash, but systematic food production also involved repetitive patterns of work, compared with the varied physical efforts of hunter-gatherers, which may have had implications for the onset and severity of degenerative joint disease. Dietary diversity and quality, however, may have suffered in the transition to settled agriculture. Evidently, maize consumption also led to dental decay. Thus, it is difficult to specify in advance the general magnitude, and even the direction, of the effect that subsistence patterns may have had on the health index. In any event, all pre-Columbian sites lacked the dietary diversity that was later provided by the addition of European plants and animals, though earlier studies suggested that health was lower after the transition to settled agriculture.[19]

Vegetation surrounding a site may have affected health via the type and availability of resources for food and shelter. Forests provided plants and animals for food, as well as fuel and housing. Semi-deserts posed greater challenges for the food supply than more lush forests or grasslands, but the dry climate might have inhibited the transmission of some diseases.

Flood plain or coastal living provided easy access to aquatic

18 As averages of the estimated beginning and ending dates of burials at particular sites, the variable YBP is artificially precise.

19 Mark Nathan Cohen and George J. Armelagos, *Paleopathology at the Origins of Agriculture* (New York, 1984). We also classified climate as temperate, semitropical, or tropical but found no connection with the health index, probably because these climate categories were too crude. This subject merits additional study.

sources of food; enabled trade compared with more remote, interior areas; and facilitated the disposal of waste. Trade, however, may have promoted the spread of disease. The uneven terrain of hilly or mountainous areas may have held advantages for defense, but could have led to more accidents and fractures.

Elevation affects, or is correlated with, temperature, insect vectors, and vegetation, and is often associated with terrain, opportunities for trade, and settlement patterns. Low elevations, particularly coastal or flood plain areas, were probably rich in food and opportunities for trade, which were beneficial for health. At most low elevations in the sample, the climate was tropical or subtropical, possibly increasing exposure to disease. It is difficult to predict the effect that elevation may have had on health.

The connection between ecological variables and the health index was studied via a sequence of simple regressions (one for each ecological variable), which are given in Table 1. Although the resulting coefficients may suffer from omitted variable bias, which is discussed below, the procedure is nevertheless useful for assessing determinants of health. As expected, settlement size had a substantial and systematic negative impact; the health index of the largest settlements falls nearly two standard deviations below that of mobile groups (hunter-gathers). The index was also substantially and systematically affected by the presence of domestic plants and by living at higher elevations, in open forest or grassland, or away from coastal areas.

The last regression in the table sheds light on the issue of multicollinearity, or high correlation of the explanatory variables. The R^2 is much higher (0.68) in the multivariate case but only one of the independent variables (elevation) was statistically significant, whereas each variable was significant in the simple regressions. The most effective solution is to obtain more diverse data, that is, sites where environmental change did not occur as a package. Thus, even in the largest data set of its kind ever assembled, the desired effects are not measurable with precision. Even though the individual coefficients are roughly estimated, however, it is safe to conclude that some combination of changing environmental conditions led to deteriorating health within the sample. In the multiple regression, the coefficient on the time trend (age BP) is much smaller (0.0013 versus 0.0025) than in the simple regression, and

Table 1 Regressions of the Health Index on Ecological Variables

	REGRESSION 1		REGRESSION 2		REGRESSION 3		REGRESSION 4		REGRESSION 5		REGRESSION 6	
VARIABLES	COEFF.	SIG. AT	COEFF.	SIG. AT	COEFF.	SIG. AT	COEFF.	SIG. AT	COEFF.	SIG. AT	COEFF.	SIG. AT
Elevation												
300+ meters	−9.73	0.001									−7.17	0.027
Settlement pattern												
Dispersed or village			−8.71	0.021							−1.91	0.625
Town or urban			−14.91	0.001							−4.39	0.388
Vegetation												
Open forest—grassland					−8.39	0.006					−3.64	0.219
Subsistence plants												
Domesticates							−10.27	0.005			0.35	0.943
Topography												
Coastal									6.53	0.038	−1.66	0.622
Age BP (years before 1950)											0.0013	0.200
Constant	74.39	0.000	78.98	0.000	73.81	0.000	78.20	0.000	67.32	0.000	74.79	0.000
R^2	0.42		0.42		0.31		0.32		0.19		0.68	
Sample size	23		23		23		23		23		23	

NOTES Omitted classes: Elevation, 0–300 meters; settlement pattern, mobile; vegetation, forest, or semi-desert; subsistence plants, no domesticates; topography, non-coastal. The mean and standard deviation of the dependent variable are 70.5 and 8.0, respectively.
SOURCE Calculated from Western Hemisphere database.

it is statistically insignificant when controlling for ecological factors.[20]

Additional work is required to learn more about which environmental changes may have been important in explaining the pre-Columbian decline in health. For this purpose, the sample was divided into two approximately equal parts: early (pre-1500 BP) and late (post-1500 BP). Table 2 gives the sample means of the health index and of the important ecological variables in these two time periods. Between the early and the late period, the health index declined 7.74 points, from 74.20 to 66.46. Importantly, all ecological variables changed in a direction adverse to health: People moved to higher elevations, out of mobile groups, into open forest-grassland habitats, cultivated more domestic plants, and left coastal areas. Column 4 of Table 2 shows that the largest move (a shift of 0.485) was into open forest-grassland areas. Multiplying this shift by the coefficient in the simple regression (−8.39) obtains a measure of the impact of this change on the health index (−4.07 points). Column 6 of Table 2 presents similar calculations for other ecological variables. The calculations show that the rise of towns and urban areas (−2.25), the change in vegetation patterns (−4.07), and the use of domestic plants (−2.89) were also important factors in the decline of the health index in the pre-Columbian era, if each variable is taken in isolation.

The sum of all the ecological impacts is −12.25, which is 4.51 points more (in absolute terms) than the decline in the health index (−7.74). Hence, the simple accounting procedure overexplains the deterioration in health. This result is not surprising, because many of the important environmental changes occurred together. For example, domestic plants were more common in urban areas, and urban areas were typically located in open forest-grassland habitats, and so forth. To the extent that change occurred as a package, the individual regression coefficients overstate the pure effect of an ecological category.

If the transition to settled agriculture and urban, upland living

20 As valuable as the average values of the ecological variables in the Western Hemisphere over time would be, even rough estimates might be unattainable. Nevertheless, a casual inspection of the archaeological evidence makes clear that the general direction of change mirrored that in the sample. Cities and socially stratified societies, for example, were tiny in numerical importance as late as 2000 years ago, and large urban centers appeared only in the millennium before Columbus. See Richard E. W. Adams, *Ancient Civilizations of the New World* (Boulder, 1997); Stuart J. Fiedel, *Prehistory of the Americas* (Cambridge, 1992).

Table 2 Average Values of Ecological Variables in the Early and Late Pre-Columbian Periods and Their Implications for Health Change

1	2	3	4	5	6
VARIABLE	EARLY (BEFORE 1500 BP)	LATE (AFTER 1500 BP)	COL. 3 − COL. 2	REGRESSION COEFF.	COL. 4 × COL. 5
300+ meters	0.364	0.500	0.136	−9.73	−1.32
Dispersed or village	0.545	0.583	0.038	−8.71	−0.33
Town or urban	0.182	0.333	0.151	−14.91	−2.25
Open forest—grassland	0.182	0.667	0.485	−8.39	−4.07
Domesticates	0.636	0.917	0.281	−10.27	−2.89
Coastal	0.545	0.333	−0.212	6.53	−1.38
Health index	74.20	66.46	−7.74		Sum: −12.25
Sample size	11	12			

SOURCE Calculated from Western Hemisphere database.

led to a decline in health, why did it occur? Unfortunately, we cannot adequately test the several possible explanations with the data at hand. First, the shift could have been a second choice forced by resource depletion. Hunter-gatherers might have resorted to farming in response to the exhaustion of their natural sources of subsistence. If so, decline in their health prior to the rise of settled agriculture might be in evidence. Our data are insufficiently rich and abundant to explore adequately this possibility.

Second, large-scale collective efforts may have given rise to redistribution that benefited some (dominant) groups at the expense of others. Leaders may have urged settled agriculture and urban living upon their followers as a way to gain political power and control over more resources. This objective might have been intertwined with strategies for military protection, whereby fortifications, warriors, and stores of weapons were important for survival. Unlike hunter-gatherer subsistence, which involved few stores of food, settled agriculture created inventories of food that could be taxed and distributed by the politically powerful. Similarly, leaders, who could spare themselves physical labor, could force it on others in the form of building massive structures, which adversely affected health. Thus would some people haved gained while many lost in the transition. If redistribution was the primary motive, health might be expected to vary more widely in complex than in simple societies. Consistent with this line of thought, inequality in wealth or income has been greater in urban than in rural areas during the period in question.

Third, the transition might have been largely voluntary if settled agriculture, trade, and urban living created material goods and ways of life that were preferable to those available in hunter-gatherer societies. This hypothesis recognizes that improved health may not have been the only important goal within early societies. Hunter-gatherers may have been tempted to switch by the availability of such articles as shells, cloth, tools, metals, and other accoutrements of large, organized societies. In other words, settled agriculturalists may have been willing to trade consumer goods and the excitement of urban living for poorer health. Even though urban living had a well-established reputation for poor health by the eighteenth century, urban populations continued to grow by in-migration. Many newcomers were apparently willing to risk their health for jobs and other amenities of the city. These priorities may have existed in earlier millennia.

Whatever the explanation for the transition to settled agriculture, the health consequences of the change are largely unrecognized, in contrast to costs well known for the transition from agriculture to urban-industrial society. Urban death rates fell close to those in rural areas in the early twentieth century but only after significant investments in waste removal, clean water supplies, and other aspects of public health and personal hygiene. Scholars must now recognize that significant health penalties have accompanied civilization and densely settled populations for several thousand years.

COMPONENTS OF THE HEALTH INDEX Because the health index is an additive measure, decomposing and analyzing its components is relatively easy, facilitated by the fact that many of its components are age or cause-specific. Hypoplasias of the permanent incisor and canine teeth (the ones most commonly affected) begins in early childhood (typically from ages 1.5 to 4.5), for example, and its presence indicates a poor diet and/or substantial exposure to disease. To the extent that young children did not work, these lesions are insulated from the systemic physiological stress caused by regular labor. Signs of anemia (porotic hyperostosis and cribra orbitalia) also reflect nutritional deficiency in early childhood (birth to age five), but the causes are usually specific—lack of iron in the diet or the presence of parasites that deplete iron. These environmental causes often persist into adulthood. The third childhood indicator (stature) is sensitive to dietary and disease conditions early in life but also incorporates the negative consequences of work (other things being equal) throughout the growing years.

Several factors may affect the prevalence of dental disease, consisting of caries, tooth loss, and abscesses. Although archaeological research has implicated tooth shapes and minerals in the local water (presence or absence of fluoride), as well as coarse foods and grit that erode teeth, the phenomenon has been consistently linked to diet across diverse environmental settings. Specifically, diets high in starch were particularly susceptible to dental decay. Even among hunter-gatherers, however, the disease prevalence is sometimes greater among women than men because women often consume more plant foods relative to meat.[21]

Researchers have identified numerous factors associated with degenerative joint disease, including trauma, sex, bone density, and nutrition, but the primary contributor is mechanical stress. Industrial laborers, for example, display patterns of joint deterioration in relation to their habitual physical activity, eventually creating bony growths on joint margins. With progression, pitting occurs where the cartilaginous tissue covering the joint has failed, and erosion of bone on joint surfaces accompanies advanced stages of the disease.[22]

Skeletal infections (periostitis) are inflammatory responses to bacterial invasion that produce loosely organized woven bone in its unhealed form and smooth but undulating or inflated bone tissue after healing. These infections are seldom fatal when confined to small patches of bone but can lead to death if the infection progresses to vital organs. The infections are painful and usually limit mobility, dexterity, and strength. Because the *Staphylococcus* and *Streptococcus* bacteria commonly involved are nearly ubiquitous and easily invade small wounds, the infections suggest a compromised immune system that results from poor net nutrition. Hence, they provide a good index of general morbidity. Unlike stature, which reflects net nutrition during the growing years, skeletal infections occur at virtually all ages, presenting a more complete picture of morbidity over the life cycle.[23]

Age-related bone loss underlies much skeletal injury in modern industrial societies. In archaeological settings, bone loss is also a risk factor for older individuals (above age forty-five), but fractures or shattered bones are usually concentrated among older children and young adults who travel over hazardous terrain, work in dangerous occupations, or engage in warfare or otherwise become victims of violence. A review of numerous case studies shows enormous diversity in patterns of trauma. Injuries in hazardous terrain are usually expressed in trauma on the lower

21 Larsen, *Bioarchaeology: Interpreting Behavior from the Human Skeleton*. Sugar also causes caries, but this product was not introduced to the Western Hemisphere until the post-Columbian period.

22 *Ibid*.

23 *Ibid*.

limbs—for example, when a fracture of the wrist or lower radius follows from an attempt to break a forward fall. Parry fractures of the middle radius or ulna often result from efforts to ward off a blow to the head; their frequency is correlated with cranial injuries under patterns of intentional, as opposed to accidental, trauma.

Table 3 shows the regression coefficients of index components on ecological variables taken in categories. These coefficients are similar to those in the middle columns of Table 2, except that the dependent variables are components rather than the health index. The column under stature shows, for example, the coefficients estimated in six different simple regressions, one for each category of independent variable. The coefficients and their statistical significance are guides to influences on health, but results should be interpreted with caution because omitted variables could bias the coefficients. Specifications involving somewhat biased but precisely estimated coefficients are arguably preferable to unbiased coefficients with large standard errors. With this approach, attributing specific environmental mechanisms of causation to the variables can be hazardous, but the scope for interpretation is narrowed by knowledge of biological processes that affect health.[24]

The summary statistics at the bottom of Table 3 show that, with the exception of trauma, the attributes of the health index display considerable variability across sites or localities. The range is particularly large for the childhood indicators of hypoplasias and stature. Low variability for trauma is not an artifact of the scale of measurement. In the entire sample (sixty-five localities), this mean score ranged from 10.8 to 100.0 and had a standard deviation of 16.1. Evidently, trauma was relatively infrequent in the pre-Columbian period.

Unlike the other components of the health index, measured environmental variables had little effect on trauma, a result that holds in the larger sample of sixty-five localities or sites. For this reason, its determinants should be studied as a process separate from other aspects of health. As suggested above, trauma rose substantially after the arrival of Europeans, especially cranial injuries among men. Whether the post-Columbian growth of trauma in-

24 Sample sizes vary because some investigators did not record all of the components in the index. Although settlement pattern is represented by two variables, it is treated as one category.

Table 3 Simple Regression Coefficients of Ecological Variables on Components of the Health Index, Pre-Columbian Sites

VARIABLE	STATURE	HYPOPLASIAS	ANEMIA	DENTAL	INFECTIONS	DJD	TRAUMA
300+ meters	−11.18**	−28.02***	−8.78**	0.019	−15.06***	−7.15*	1.58
Dispersed or village	−13.96**	−13.43	−3.54	−6.17	−9.10	−11.54***	3.13
Town or urban	−16.01**	−32.18**	−17.77***	−3.95	−33.66***	−12.64**	4.88*
Open forest—grassland	−2.44	−21.46**	−10.18***	−5.21	−14.70**	−0.91	0.59
Domesticates	−6.13	−20.41**	−6.97*	−7.33*	−17.35***	−12.41***	2.79
Coastal	−0.54	16.69*	6.14	7.13**	13.71**	7.99**	1.60
Mean	15.09	73.60	88.98	83.77	75.20	78.82	90.74
Standard deviation	14.91	22.97	11.19	10.45	16.99	11.11	5.29
Minimum	0.40	18.70	55.00	55.30	45.20	51.40	80.20
Maximum	59.80	99.70	100.00	100.00	98.70	100.00	100.00
Sample size	33	28	35	36	34	36	34

NOTES Using two-tailed tests, * = significant at 0.10; ** = significant at 0.05; *** = significant at 0.01.
SOURCE Calculated from the Western Hemisphere database.

volved direct conflict between Europeans and natives or resulted from tribal warfare precipitated by European presence is unknown at this point.[25]

Coastal living was advantageous for health particularly with regard to infections, dental health, and DJD. With the possible exception of hypoplasias, however, coastal living did not protect children, which indicates that adults were the primary beneficiaries. Diverse patterns of work and subsistence, combined with lower intensity of physical effort, were likely to have eased degenerative joint disease in coastal areas.

All childhood indicators, as well as infections and possibly DJD, worsened at high elevations, but this environment had no systematic consequence for dental decay. Why the greater subsistence challenges at higher elevations were not expressed in dental decay is a mystery. It is worth investigating whether the water at these sites contained minerals that protected teeth.

URBANIZATION AND HEALTH The large and systematic negative impact of urban living merits additional discussion. The urban populations occupied six of the ten lowest slots in the health-index rankings across the twenty-three pre-Columbian sites, averaging 64.1 compared with an overall mean of 70.5, and a mean of 80.2 among the sites having the six highest scores. What kind of story can be told about the pathways by which urban living adversely affected health in this era? Unfortunately, opportunities for statistical analysis are severely constrained by lack of surviving evidence. In general, reliable population densities are difficult to calculate, for example, because excavations are incomplete. Total population size is not ascertainable without knowledge of the number and distribution of dwellings. Moreover, the number of residents may have fluctuated in ways that are hard to estimate from archaeological remains. Connecting any possible fluctuations in population size with precise burial dates is also a considerable challenge.

None of the urban centers prospered early in the pre-Columbian era, but they span a reasonably wide range of time, from approximately 100 to 1160 A.D. All of them were located in

25 Phillip L. Walker and Steckel, "A Western Hemisphere Perspective on the History of Violence," paper presented at the Fourteenth European Meeting of the Paleopathology Association, Coimbra, Portugal, August 31, 2002.

Mesoamerica, three in the basin of Mexico, and three along or near the coast of the Yucatan peninsula or Honduras; the condition of the three coastal settlements contradicted any simple connection between coastal living and good health. Notwithstanding the hazards involved in the estimation of population size, these cities are thought to range from just under 10,000 to roughly 100,000 to 150,000 residents. By way of comparison, among northern Europe's few urban areas, Paris and Mainz had no more than 25,000 people in 1000 A.D. As late as the end of the thirteenth century, significant urbanization was confined mainly to southern Europe, in such northern Italian towns as Milan, Florence, Venice, and Genoa, each of which probably exceeded 100,000 in population. At this time, Paris was the only city in northern Europe that may have fallen into this category. The southern Low Countries were moderately urbanized by the late Middle Ages (the fourteenth century), but the largest city, Ghent, probably had no more than 50,000 inhabitants. London and Cologne held fewer than 40,000 people at this time.[26]

Life in a paramount town or urban area was devastating for infections, and hard on the childhood indicators (hypoplasias, stature, and anemia) and on DJD. The regression coefficients of Table 3 for towns/cities were statistically significant and large relative to the standard deviations of the independent variables. Although it is difficult to allocate the effect of urban living between the pure effects of population size versus its association with other measured variables, large statistically significant effects are unlikely to have been primarily the result of specification bias. Use of domesticates (plants) was bad for degenerative joint disease, dental health, hypoplasias, and infections, but unlike urban living, had no systematic consequences for stature, suggesting that older children living in cities and towns had avenues of nutritional protection that were unavailable to young children.

Three features of urban areas have been associated with poor health in studies of periods prior to the late nineteenth century: heavy exposure to communicable diseases created by congested living and poor sanitation; inequality of wealth, power, and work effort; and a relatively high cost of food. How do these explana-

26 Jan De Vries, *European Urbanization, 1500–1800* (Cambridge, Mass., 1984); Paul W. Hohenberg and Lynn Hollen Lees, *The Making of Urban Europe, 1000–1950* (Cambridge, 1985).

tions fare in the pre-Columbian world? Because the skeletal infections usually stem from *Staphylococcus* or *Streptococcus* bacteria, which were also abundant in rural areas, the high infection rates in cities probably did not stem from elevated exposure to pathogens. Instead, the infections signify a weak immune system connected with poor net nutrition. The argument that they were the result of food prices higher than those in rural areas is deflated by the fact that three out of six cities were on or near the coast, with easy access to marine sources of food and to low-cost transportation of food imports.

Instead, high rates of degenerative joint disease in the cities points to work effort, which drains net nutrition, as a significant culprit. The monumental architecture and the rituals associated with it in pre-Columbian cities of Mexico and the Yucatan region were emblems of a highly stratified society. Monuments were built by masses of laborers with simple tools, without the help of draft animals. Inequality in access to food and housing likely compounded the biological stress created by hard work.

The available package of evidence does not eliminate high food prices and heavy exposure to pathogens as factors adverse to health in pre-Columbian cities. Although the state of research is far removed from definitively assigning numeric weights to causal elements, inequality and draining physical effort are the leading contenders.

IMPLICATIONS Some historians have argued that the absence of many prominent European diseases such as smallpox, measles, and typhoid among native populations created an epidemiological Garden of Eden. Some have speculated that these conditions allowed an enormous population to flourish. The skeletons, however, tell a much more complicated story. Pre-Columbian Native Americans at sixty-five localities occupy the highest and the lowest slots in the rankings of the health index, which also include post-Columbian natives plus fourteen groups of European-Americans and African-Americans. The absence of several major European diseases does not prove a benign disease environment or good health. Numerous native populations, particularly ones that lived late in the pre-Columbian period, were riddled with pathological lesions. The natives encountered by Christopher Columbus either acquired or evolved with pathogens, which interacted with their subsistence patterns and other life ways, to cause substantial morbidity and shorten life.[27]

The spread of European diseases has been noted as a major factor in the rapid Spanish conquest of Central and South America. This article and other work in anthropometric history suggest that the poor nutrition of many native populations, including those rapidly conquered, has been overlooked. The impact of European diseases and the advantages conveyed by surprise, guns, and steel are not to be underestimated, but the sharp contrast with the circumstances of tribes native to the nineteenth-century Great Plains is undeniable. With similar technology (guns and horses) and good nutrition (measured by tall stature and a diverse-high-protein diet) and despite the heavy burden of such European diseases as smallpox and measles, the Plains tribes were more than a match in conflicts with their eventual conquerors. Indeed, destruction of their major food source—the bison—was a key ingredient in their eventual demise.[28]

There are plausible mechanisms by which good nutrition conveys benefits in times of conflict. The first is physical energy to organize and resist. Even without stores of food at hand, well-nourished people have large reservoirs of tissue (fat and muscle) that can be metabolized over a period of days or weeks. Well-nourished populations also tended to have food stores, which could provide the energy necessary to prolong conflict and impose higher costs on invaders whose supply lines were stretched by expeditions to the interior. Poor nutrition weakens the immune system, and when combined with the physical demands of mobilization and the burden of disease, would have sapped vigor. Although the topic is still under study, poor nutrition for the masses appears to have been associated with inequality in material resources and access to power. The relatively disadvantaged may have been not only less able by reason of poor diet, but also by decreased enthusiasm.

27 For a general discussion of health in pre-Columbian American, see Kenneth F. Kiple and Stephen V. Beck, *Biological Consequences of the European Expansion, 1450–1800* (Brookfield, Vt., 1997). Steckel, Sciulli, and Rose, "A Health Index from Skeletal Remains."

28 Joseph M. Prince and Steckel, "Nutritional Success on the Great Plains: Nineteenth-Century Equestrian Nomads," *Journal of Interdisciplinary History,* XXXIII (2003), 353–384.

Many scholars maintain explicitly or implicitly that the European advance would have been much different without the disease weapon; the invasion might have failed or stalled, substantially altering world history. Counterfactual speculation from another standpoint might be instructive: All things being equal, would good nutrition alone have tipped the balance, enabling natives to repel the invaders? What might have happened, for example, if a high protein food source (cattle or bison) had been readily available in the cities of central Mexico and other poorly nourished areas? The idea is hardly farfetched; military history repeatedly demonstrates the value of food.

Geographical determinism was vastly oversold in the early twentieth century, but scholars have recently resurrected useful elements of the idea. Economists have investigated the effect of the physical environment on persistent differences in economic performance. Based on cross-country comparisons, they have measured the disadvantages of tropical location, for example, on GDP per capita. The most interesting questions now on this agenda involve the likely pathways or mechanisms underlying the relationship. Skeletons suggest that the physical environment has long been relevant for human success or failure. The connection observed in recent times may not be simply the by-product of such modern forces as colonialism, institutions, or government policy. Further study will tell.[29]

Demographic data available for the past couple of centuries repeatedly show that cities had relatively high death rates prior to the twentieth century; a decline in health often accompanied industrialization, particularly in its urban locations. The skeletal evidence suggests that health costs of human aggregation long predated industrialization, however, possibly extending back to the earliest urban centers. Numerous social scientists have celebrated the early rise of civilization as an enormous human achievement that gave rise to government, law, urbanization, interregional trade, new architecture, and so forth. But scholars have considered mainly the asset side of the ledger, implicitly viewing the transition as an ancient free lunch. Significant health penalties also accompa-

29 Jeffrey D. Sachs, "Tropical Underdevelopment," National Bureau of Economic Research Working Paper No. 8119 (Cambridge, Mass., 2001).

nied early, large-scale human organization, and these costs should be recognized and incorporated into historical research.

Although incomplete as a measure of health, skeletons are valuable as a gauge of social performance across millennia. Far more informative than stature alone, skeletal measures are not only available across vast stretches of time and space; they are also comparable over this expanse in ways that dwarf anything available for traditional measures of human welfare.

Skeletal health will be useful in debates about the prime movers of extremely long-term economic growth, helping to determine the extent to which technological progress can be explained as the result of the endogenous choices of profit-maximizing innovators. According to the theories of Hansen/Prescott and Galor/Weil, per capita consumption should have been largely constant before the era of modern growth, whereas Jones allows for periods during which human welfare improved measurably because of bursts in innovative activity or unusually favorable institutional changes. Jones' model is an alternative to the null hypothesis proposed by the Hansen/Prescott and Galor/Weil models.[30]

Skeletons have promising applications in studying human adaptation to climate change, a topic inspired by growing concerns about global warming. From tree rings, ice cores, and other sources, climate historians have made considerable progress in measuring important aspects of climate over many thousands of years. Climate historians, such as deMenocal, have used new evidence to link climate change to the fall of the Maya. Although the fall of civilizations is interesting, it is a crude measure of social performance. Linking skeletal health with climate data far more detailed than collected for the Western Hemisphere project will eventually enable scholars to measure the connection between climate and human welfare with greater precision.[31]

30 Gary D. Hansen and Edward C. Prescott, "Malthus to Solow," *American Economic Review,* XCII (2002), 1205–1217; Oded Galor and David N. Weil, "Population, Technology, and Growth: From Malthusian Stagnation to the Demographic Transition and Beyond," *American Economic Review,* XC (2000), 806–828.

31 Brian M. Fagan, *The Little Ice Age: How Climate Made History, 1300–1850* (New York, 2000); Peter B. deMenocal, "Cultural Responses to Climate Change During the Late Holocene," *Science,* CCXCII (2001), 667–673.

The National Science Foundation recently funded a project that will gather and study substantial amounts of skeletal data from European populations that lived from the Paleolithic era to the late nineteenth century. This research laboratory is enriched by an enormous diversity in conditions that were likely important for social performance throughout the millennia, including technology, climate, social organization, political structure, degree of urbanization, and opportunity for trade. When combined with evidence from archaeology, historical documentation, climate history, GIS, and other sources, skeletal data can contribute to a wide range of topics, including the health of women and children, long-term trends in patterns of trauma and violence, biological inequality, aging and health, geographical patterns of health, migration patterns informed by ancient DNA, and the co-evolution of humans and disease as shown by the DNA of ancient pathogens.[32]

32 Additional information can be found on the project's web page, http://global.sbs.ohio-state.edu.