Measuring Social Performance over the Millennia:

The Long-Term Decline in Health in Pre-Columbian America

By

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Abstract

Lack of evidence has been the major obstacle to understanding trends and differences in human welfare over the millennia. This paper explains and applies methods that are obscure to most academics and essentially unknown to the general public. A millennial perspective is best obtained from skeletal remains, which depict not only childhood health conditions but also processes of degeneration that accompany aging and strenuous physical effort. Compiled into an index of health, data from 65 localities as part of a large collaborative project on the Western Hemisphere reveal a long-term decline in health in pre-Columbian America, a trend driven by population movements into less healthy ecological environments. The approach can shed light prime movers of long-run economic growth, human adaptation to climate change, and the effects of geographic conditions on social performance.

When and why industrial countries became rich and healthy are important questions in economics that form the core of subject matter in economic history. Some aspects of the process are understood from estimates of life expectancy and of GDP, which have been constructed as far back as the nineteenth century for several countries. In the past quarter century anthropometric historians, who study nutritional status using heights from slave manifests, military records and many other sources, have added another century to the window of evidence on social performance.

This paper vastly extends the reach of anthropometric history by describing methods and results using skeletal remains, which depict important aspects of well being over the millennia, thereby embracing human activities from the era of hunter gathers onward to settled agriculture, the rise of 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 the life cycle. As a package the skeletal measures provide age and source-specific detail on biological stress from early childhood through old age. The remains also exist for women and for children, two groups often excluded from more familiar historical sources such as tax documents, muster rolls, and wage records. Thus, skeletons provide a more extensive and complete picture of community health than available from historical records on stature. Trends and differences in skeletal health can be analyzed when combined with data from archaeology, historical documents, climate history, Geographic Information Systems (GIS) databases and other sources.

Data on skeletal health have numerous applications, including debates over the prime movers of very long-term economic growth, incentives to invest in human capital, the rise and fall of civilizations, and human adaptation to their physical environments. Economists, historians and political scientists have identified inequality, not only in income or wealth, but also in the form of disparities in health and nutrition, as a driving force in social, political and economic change. Thus, health has played a central role in human history, both as an agent of change and as an outcome measure indicating the quality of life.

The specific application involves the health of the aboriginal population of the Western Hemisphere prior to the arrival of Europeans. The results follow from a large collaborative project involving economists, historians and physical anthropologists, who assembled numerous measures of skeletal health from more than 12,000 individuals who lived in the Western Hemisphere over the past several millennia. Sampling issues inevitably arise in the comparative study of skeletons and there are ambiguities in interpreting this biological evidence. Confidence in the approach is bolstered, however, by comparing results with patterns of health that are well established from other sources.

Measures of Biological Stress

Skeletons furnish the best and, in many cases, the only picture of health available over the millennia. Because this evidence is obscure to most social scientists, it is useful to begin with a general discussion of skeletal manifestations of stress.[1] 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. 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 (Clark Spencer Larsen, 1997). Hunter-gatherers who walked long distances, for example, had oval-shaped femurs but these bones were nearly circular among settled agriculturalists who 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 use.

Net nutrition has been an effective 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.[2] If net nutrition is insufficient, growth slows or ceases, and linear growth of the skeleton is stunted if the deprivation is chronic and severe.

In principle, anthropologists could use any bone to estimate stature but the femur is often well preserved and easily measured, and therefore is widely used. Among the skeletal elements the femur also has the greatest correlation with stature, in part because it comprises about one quarter of standing height. (Mildred Trotter and Goldine C. Gleser, 1952) conducted the classic study relating height to femur length. Seeking information useful in forensics, they estimated the relationship between the two variables using femur lengths of the deceased 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 problematic until the bony components of the femur fuse late in the teenage years.

As a group, physical anthropologists collect hundreds of skeletal measures, many of which are very specialized in nature and some of which reflect rare or unusual forms of physiological stress.[3] In designing a study of community health with a large number of collaborators, it is important to select general health indicators that are understood and reported by virtually all physical anthropologists, regardless of specialty. In a large collaborative study that investigated skeletal health over the past several thousand years, these included three indictors 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 which are more prevalent among older children and adults (skeletal infections and trauma).[4] Stature has already been discussed as a child health indicator, and the others are briefly explained below (for more information see (Clark Spencer Larsen, 1997)) and (Tim D. White and Pieter A. Folkens, 2000)) and references therein).

Enamel hypoplasias (linear enamel defects). Hypoplasias are 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. The disruption is usually environmental, commonly due to either poor nutrition or infectious disease or a combination of both. Although nonspecific, hypoplasias are informative about physiological stress in childhood 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. In circumstances where 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 most readily visible in the skeletons of young children in areas where red blood cell production occurs, such as in 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. The lesions can also be caused by other factors, but iron deficiency is among the most common causes. 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 and physical activity.

Dental health. Dental health is an important indicator both of oral and general health, which is assessed in archaeological skeletons from dental caries, antemortem tooth loss, and abscesses. 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 from 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 bone 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 (especially the tibia), have been documented worldwide. Most of these lesions are found as plaque-like deposits from periosteal inflammation, swollen shafts, and irregular elevations on bone surfaces. Most lesions are nonspecific but they often originate with *Staphylococcus* or *Streptococcus* organisms. These lesions have proven very informative about patterns and levels of community health in the human past.

Trauma. Fractures, weapon wounds, and other skeletal injuries provide a record of accidents or violence. Accidental injuries, such as ankle and wrist fractures, reflect difficulty of terrain and the hazards of specific occupations. Injuries caused by violence, such as weapon wounds or parry fractures of the forearm, provide 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. While death is usually well defined, morbidity is much less precise. The incidence of various chronic diseases, days lost from school or work, and assessments of physical capacity are used, but all have conceptual limitations. Moreover, gathering reasonably comprehensive morbidity information that is accurate 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.

How effective are skeletons in capturing the elements of health? At most localities or burial sites, a useful but incomplete picture is available for morbidity. Estimates of life expectancy will be improved by new techniques of aging, but remain hazardous without good contextual information about the population from archaeological and other sources. Lack of information on life expectancy is less damaging than it might appear for the study of health, however. To the extent that morbidity and mortality are positively correlated, health can still be indexed or ranked across sites by using morbidity indicators from skeletons.[5]

Skeletons are good at summarizing several types of chronic morbidity, with the exception of various soft-tissue conditions such as hernias or torn ligaments. Degenerative joint disease and dental decay often develop over many years, and both have adverse functional consequences. DJD is painful and limits mobility, whereas dental decay limits the ability to chew and digest a coarse diet, which 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 and the adverse environmental conditions that created these bony malformations tend to persist thereafter. Skeletal infections are often painful and signal a weakened immune system that can lead to illness and functional loss. Broken bones and weapon wounds are painful and 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. Hunger is painful and limits physical activity in the fashion of anemia, and hypoplasias are usually the direct result of severe bouts of 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, one can seldom argue that skeletons represent an entire society. Many collections in Europe, for example, are disproportionately from cities and towns, where much construction has occurred relative to rural areas.

These constraints are a hindrance but far from disabling. In formulating a large comparative project involving numerous sites, one may stratify to obtain adequate representation from rural and urban areas. Post-weighting samples is a second option. As discussed below, one may 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.[6] Ideally both life expectancy and morbidity would be available, so that one might roughly approximate a measure such as quality-adjusted life years. Unfortunately many sites in the collaborative project lack reliable estimates of life expectancy. Therefore the health index discussed here incorporates only morbidity as expressed in the frequency and severity of skeletal lesions, but the index could be adapted to incorporate length of life. A positive correlation between morbidity and mortality is likely, however, which 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.

The index was estimated from the 12,520 skeletons of individuals who lived at 65 localities in the Western Hemisphere over the past several thousand years, 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). Thus, 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, which is justified by knowledge that childhood deprivation negatively affects adult health.[7] The duration of morbidity prior to death is in fact unknown for the remaining four components (infections, trauma, DJD, and dental decay) but it is clear these skeletal lesions reflect chronic conditions that typically persisted for several years. While the durations are the subject of ongoing research, on a provisional basis they were assumed to have existed for 10 years prior to death.

(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 roughly agree with pre-Columbian mortality conditions in the Western Hemisphere. The results were multiplied by life expectancy in this reference population and expressed as a percent of the maximum attainable, which corresponds to a complete lack of skeletal defects or lesions.[8] This procedure effectively denudes the

health index of differences or variations in mortality rates because all populations are assumed to have had the same life expectancy.[9]

(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, which cannot be pursued in a brief paper. It would be appropriate to weight the elements of the index, such as dental decay and trauma, by their functional consequences but this is complicated by the nature of the social safety net, medical technology and other factors that vary in unknown ways across societies. Thus, equal weighting is questionable but it is also difficult to justify an alternative scheme given the present state of knowledge. In addition, the index is an additive measure that ignores interactions, but having 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 the imposition of justifiable interaction effects.[10]

A Test of the Methodology

Comparing results with patterns well established in historical studies is a useful technique for assessing the health index as a work in progress.[11] Settlement size is a suitable category because a great deal is known about this 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 led to the accumulation of 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—and therefore large differences in access to resources and in work effort, which were important for health. These same processes affecting health likely existed in the pre-Columbian world. Other things being equal, one would expect the more mobile, less densely settled populations to have been healthier than those living in paramount towns or urban areas.

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 at 23 localities in North, Central and South America. (Richard H. Steckel and Jerome C. Rose, 2002b) used archaeological evidence to arrange the settlements into three types: mobile (essentially hunter gatherers); village or settled but dispersed populations; and town or paramount urban center.[12] The estimated regression of the health index on settlement type is:

$$HI = \underset{(0.000)}{78.98} \underset{(0.021)}{-8.71}\ Village \underset{(0.001)}{-14.91}\ Urban, N = 23, R^2 = 0.42 \qquad (1)$$

where significance levels are given in parentheses, and the mean and standard deviation of the dependent variable are 70.5 and 8.0, respectively (Richard H. Steckel and Jerome C. Rose, 2002b). The coefficients are both statistically and practically significant: the health index was nearly two standard deviations lower in the largest population setting as opposed to mobile groups.

That the health index systematically declined with increasing settlement size is welcome news for the methodology. The index has passed an important preliminary test, suggesting 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. Figure 1 shows a scatter diagram of the health index at 23 pre-Columbian (pre-1492) sites where all seven attributes were reported by the different research teams. The downward trajectory is statistically significant in a simple linear regression:

$$HI = \underset{(0.000)}{65.41} + \underset{(0.009)}{0.0025}\ YBP, \; N = 23, \; R^2 = 0.53 \qquad (2)$$

Significance levels are shown in parentheses. Regrettably, few sites were located in the early pre-Columbian period. There are only three data points before approximately 1000 BC, which complicates the interpretation of the time trend. This particular scattering of sites imparts a high standard deviation to the independent variable ("time"), which one could argue, artificially shrinks the standard error of the time coefficient, i.e., a few chronological outliers may heavily affect the estimated relationship. This 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.

Additional measurable variables collected for each site include food sources, vegetation, topography, elevation, and settlement pattern. While it is impossible to specify in detail the pathway of causation for each of these variables, 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 relation between diet and the health index, however, is made complex by interactions with other ecological variables such as topography, climate, settlement size, and trade. While settled agriculture provided a greater supply of foods such as maize, beans, and squash, 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. It is also thought that dietary diversity and quality may have suffered in the transition to settled agriculture. In addition, there is evidence that maize consumption led to dental decay. Thus, it is difficult to specify in advance the general magnitude and even the direction of 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. Based on earlier studies, however, one might expect that health was lower after the transition to settled agriculture (Mark Nathan Cohen and George J. Armelagos, 1984).

Vegetation surrounding the site may have affected health via the type and availability of resources for food and shelter. Forests provided materials for the diet, fuel and housing and also sheltered animals that could have been used for food. Semi-deserts posed challenges for the food supply relative to 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 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. Uneven terrain found in hilly or mountainous areas may have provided advantages for defense, but could have led to more accidents and fractures.

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

The connection between ecological variables and the health index was studied using 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, with the health index of the largest settlements falling nearly two standard deviations below that of mobile groups (hunter gathers). The index was also substantially and systematically affected by use of domestic plants, 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. 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, i.e. sites where environmental change did not occur as a package. Thus, despite having the largest data set of its kind ever assembled, the desired effects are not measurable with precision. Even though the individual coefficients are imprecisely estimated, however, it is safe to conclude that some combination of changing environmental conditions led to deteriorating health. 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 it is statistically insignificant when controlling for ecological factors.

Additional work is required to learn more about which environmental changes may have important in explaining the pre-Columbian decline in health. For this purpose the sample was divided into two roughly 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 from 74.20 to 66.46, a difference of 7.74 points. 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, used 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, and by multiplying this shift by the coefficient in the simple regression (-8.39), we obtain 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 changes is –12.25, which is 4.51 points more than the decline in the health index (-7.74). Therefore the simple accounting procedure over-explains the deterioration in health. This is not surprising because many of the important environmental changes occurred together, e.g. domestic plants were more commonly used in urban areas and urban areas were more typically located in open forest-grassland habitats, etc. 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 led to a decline in health, why did it occur? There are several possible explanations, but unfortunately we cannot adequately test them with the data at hand. First, the shift could have been a second choice forced on hunter-gathers by resource depletion. They might have farmed in response to exhaustion of natural sources of subsistence. If correct, one would expect to observe a decline in health prior to the rise of settled agriculture. 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, where few stores of food existed, settled agriculture created inventories of food that could be taxed and distributed by the politically powerful. Similarly, the powerful expended less energy on work and were able to compel work, such as building monuments, which adversely affected health. Thus, some people gained while many lost in the transition. If redistribution was the primary motive, one might observe greater inequality in health in more complex relative to less complex societies. Consistent with this line of thought, inequality in wealth or income has been greater in urban versus rural areas in the historic period.

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 availability of articles such 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. By the eighteenth century urban living had a well-established reputation for poor health, yet populations of these areas continued to grow by in-migration. Many newcomers were apparently willing to risk their health for job and amenities of the city, and it is plausible to think that 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, only after people made 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 the past several thousand years.

Unpacking the Health Index

The health index is an additive measure, which makes it easy to decompose and analyze its components, an effort facilitated by knowledge that many of its components are age or cause-specific. Hypoplasisas of the permanent incisor and canine teeth (the ones most commonly affected) are formed in early childhood (typically from ages 1.5 to 4.5), for example, and their presence indicates a poor diet and/or substantial exposure to disease (Clark Spencer Larsen, 1997). To the extent that young children did not work, these lesions are insulated from its effects on systemic physiological stress.

Signs of anemia (porotic hyperostosis and cribra orbitalia) also reflect nutritional stress in early childhood (birth to age 5), but the causes are usually quite specific: lack of iron in the diet or the presence of parasites that absorb iron (Clark Spencer Larsen, 1997). These environmental causes often persist into adulthood. The third childhood indicator (stature) is sensitive to dietary and disease conditions in early childhood 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 (Clark Spencer Larsen, 1997). Specifically, diets high in starch (and especially maize in the pre-Columbian Western Hemisphere) have led to dental decay. [13] Even among hunter-gatherers, however, the disease prevalence is sometimes greater among women compared with men because the former often consume more plant foods relative to meat.

Researchers have identified numerous factors associated with degenerative joint disease, including trauma, sex, bone density and nutrition, but the primary contributor is mechanical stress (Clark Spencer Larsen, 1997). Industrial laborers, for example, display patterns of joint deterioration in relation to habitual physical activity at work, which eventually leads to bony growth 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.

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 inflections 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 *Staph* and *Strep* 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 are a good index of morbidity more generally. Unlike stature, which reflects net nutrition during the growing years, skeletal infections occur at virtually all ages and therefore provide a more complete picture of morbidity over the life cycle.

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 45) 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 interpersonal violence. A review of numerous case studies shows enormous diversity in patterns of trauma (Clark Spencer Larsen, 1997). Injuries in hazardous terrain are usually expressed in trauma on the lower limbs, as 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, and 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 6 different simple regressions, one for each category of independent variable.[14] 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. In my view, it is preferable to consider specifications involving somewhat biased but precisely estimated coefficients than unbiased coefficients with large standard errors. With this approach it can be hazardous to attribute specific environmental mechanisms of causation to the variables, but the scope for interpretation is narrowed by knowledge of biological processes that affect health.

The summary statistics at the bottom of Table 3 show that with the exception of trauma, the attributes of the health index displayed considerable variability across sites or localities. The range was particularly large for the childhood indicators of hypoplasias and stature. Low variability for trauma was not an artifact of the scale of measurement; in the entire sample (65 localities) this mean score ranged from 10.8 to 100.0 and had a standard deviation of 16.1. Therefore 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 65 localities or sites. Therefore its determinants should be studied as a process separate from other aspects of health. As suggested above, trauma did rise substantially after the arrival of Europeans, especially cranial injuries among men (Phillip L. Walker and Richard H. Steckel, 2002). At this point it is unknown whether the post-Columbian growth of trauma involved direct conflict between Europeans and natives or resulted from tribal warfare precipitated by European presence.

Coastal living was advantageous for several aspects of health, particularly infections, dental health and DJD. With the possible exception of hypoplasias, however, coastal living did not protect the 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 suffered at high elevations, but this environment had no systematic consequence for dental decay. As a tendency, subsistence was more challenging at higher elevations, but it is unknown why this was not expressed in dental decay. 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 6 of the 10 lowest slots in the health index rankings across the 23 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 6 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 one cannot reliably calculate population densities, for example, because excavations are incomplete, making it difficult to determine total population size from counts of the number and distribution of dwellings. Moreover, the number of residents may have fluctuated over time 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 AD. All were located in Mesoamerica, 3 in the basin of Mexico and 3 along or near the coast of the Yucatan peninsula or Honduras, the condition of latter group contradicting any simple connection between coastal living and good health. As noted, estimation of population size is hazardous, but it is thought that these cities ranged from just under 10,000 to roughly 100,000 to 150,000 residents. By way of comparison, northern Europe had few urban areas, with Paris and Mainz no larger than 25,000 people in 1000 AD (Tertius Chandler, 1987, p. 538). As late as the end of the 13th century, significant urbanization was confined mainly to southern Europe, in northern Italian towns such as Milan, Florence, Venice and Genoa, each of which probably exceeded 100,000 in population (for a discussion of urban growth see Paul W. Hohenberg and Lynn Hollen Lees, 1985). 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 14th century), but the largest city, Ghent, probably had no more than 50,000 inhabitants, while London and Cologne held fewer than 40,000 people at this time.

Living in a paramount town or urban area was devastating for infections, and hard on the childhood indicators (hypoplasias, stature, and anemia) and on DJD, where the regression coefficients of Table 3 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 was bad for degenerative joint disease, dental health, hypoplasias and infections, but unlike urban living, had no systematic consequences for stature, which suggests 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 the historical period 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 relatively high cost of food. How do these explanations fare in the pre-Columbian world? Because the skeletal infections usually stem from *Staph* or *Strep* bacteria, which were also abundant in rural areas, the high infection rates in cities cannot be blamed on elevated exposure to pathogens. Instead, the infections signify a weak immune system connected with poor net nutrition. The latter might follow from food prices that were high relative to rural areas, but this argument is deflated by the fact that 3 out of 6 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 pre-Columbian cities of Mexico and the Yucatan region were noted for their monumental architecture. These and the rituals associated with their use were emblems of a highly stratified society. The monuments were built with simple tools, without draft animals and therefore with much human physical effort undertaken by masses of people. Inequality in access to food and housing likely compounded the biological stress created by their hard work.

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

Two Implications

Historians have noted the absence of many prominent European diseases such as smallpox, measles and typhoid in arguing that native populations were generally healthy, perhaps living in an epidemiological Garden of Eden.[15] Some people have speculated that these conditions allowed an enormous population to flourish. Instead the skeletons reveal enormous diversity, with pre-Columbian Native Americans occupying the highest and the lowest slots in the rankings of the health index at 65 localities, which also include 14 groups of European-Americans and African Americans. The absence of several major European diseases does not prove there was 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 Columbus either brought or evolved with pathogens, which interacted with their life ways, to cause substantial morbidity and shorten life.

Economists have investigated the consequences of the physical environment on economic performance (Jeffrey D. Sachs, 2001). 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. The skeletons suggest that the physical environment has long been relevant for human success or failure. While the matter deserves far more study, the long association suggests that the connection observed in recent times may not be simply the bi-product of modern forces such as colonialism, institutions or government policy.

Agenda

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

Skeletal health will be useful in debates over the prime movers of very long-term economic growth, harnessed to test explanations flowing from efforts to model technological progress as arising from endogenous choices of profit-maximizing innovators. According to the Hansen-Prescott theories, per capita consumption should have been essentially constant before the era of modern growth, whereas the Jones explanation allows for periods during which human welfare improved measurably because of bursts in innovative activity or unusually favorable institutional changes (Gary D. Hansen and Edward C. Prescott, 2002, Charles I. Jones, 2001). Jones' model can therefore be regarded as proposing the alternative hypothesis to the null hypothesis proposed by the Hansen/Prescott and Galor/Weil models.

Skeletons have promising applications in studying human adaptation to climate change, a topic inspired by growing concerns over 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 (Brian M. Fagan, 2000). Climate historians such as (Peter B. deMenocal, 2001) have used the new evidence to link climate change to the fall of the Maya. While the fall of civilizations is interesting, it is a crude measure of social performance. By linking skeletal health with new climate data, it will be possible to measure the connection between climate and human welfare with greater precision.

The National Science Founded 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.[16] This research laboratory is enriched by enormous diversity in conditions that were likely important for social performance over the millennia, including technology, climate, social organization, political structure, degree of urbanization and opportunities for trade. When combined with evidence from archaeology, historical documents, climate history, GIS and other sources, the skeletal data can be used to investigate a wide range of topics such as the health of women and children; long-term trends in patterns of trauma and violence; biological inequality; aging and health; geographic patterns of health; migration patterns informed by ancient DNA; and the co-evolution of humans and disease using the DNA of ancient pathogens.

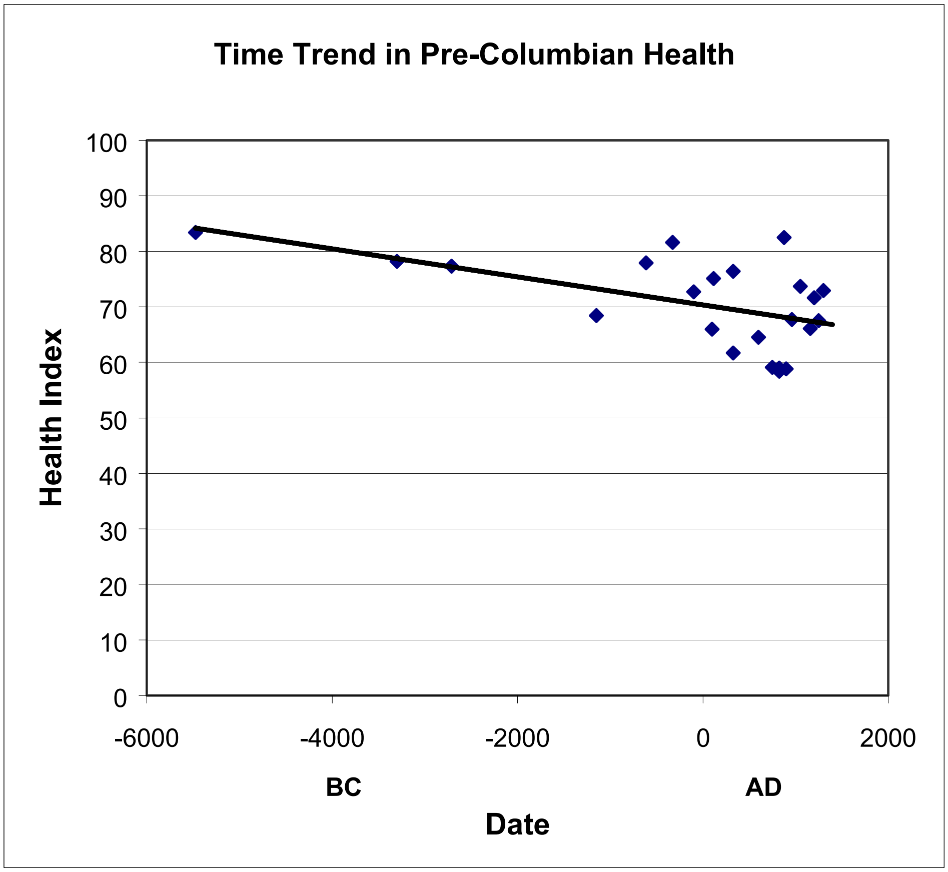

Figure 1. Time Trend in Pre-Columbian Health

Note: Deterioration in health is indicated by the downward trend of the linear regression line associated with these points (R^2=0.53; $p \leq 0.05$). The health index declined by an average of 2.5 points per millennium.

Source: See text.

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.	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											0.0013	0.200
Constant	74.39	0.000	78.98		73.81	0.000	78.20	0.000	67.32		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	

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.

Table 2: Average Values of Ecological Variables in the Early and Late in the 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 x 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.

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	0.4	18.7	55.0	55.3	45.2	51.4	80.2
Maximum	59.8	99.7	100.0	100.0	98.7	100.0	100.0
Sample size	33	28	35	36	34	36	34

Source: Calculated from the Western Hemisphere database.

Notes: Using two-tailed tests, * = Significant at 0.10; ** = significant at 0.05; *** = significant at 0.01.

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Footnotes

[1] For discussion and references to the literature, see White and Folkens (2000) and Goodman and Martin (2002).

[2] Tanner (1978); Steckel (1995).

[3] For a discussion see Buikstra and Ubelaker (1994).

[4] For additional details see (Steckel and Rose, 2002)

[5] This conclusion is bolstered by morbidity and mortality data analyzed in Arora (2002).

[6] A short paper necessarily conveys only a flavor of the methodology; for additional details and justification see Steckel, Sciulli and Rose (2002). Presumably future research will lead to more appropriate assumptions and an improved health index.

[7] The effect of fetal and early childhood health on adult health is sometimes called the Barker hypothesis, which is discussed in Barker (1998). For a additional discussion see Fogel and Costa (1997).

[8] The Model West level 4 population has a life expectancy at birth of 26.4 years. For a discussion of model life tables see Coale and Demeny (1966).

[9] Known differences in life expectancy could be incorporated easily into a modified index. Changing the life expectancy modifies the weights but not the age-specific rates.

[10] For a discussion of interaction effects in a modern context see Torrance and Feeny (1989).

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

[12] Steckel and Rose (2002b).

[13] Sugar also causes caries but this product was introduced to the Western Hemisphere in the post-Columbian period.

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

[15] For a general discussion of health in pre-Columbian America see Kiple and Beck (1997).

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