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Biological Measures of the Standard of Living

Richard H. Steckel

When economists investigate long-term trends and socioeconomic differences in the standard of living or quality of life, they have traditionally focused on monetary measures such as gross domestic product—which has occupied center stage for over 50 years. In recent decades, however, scholars have increasingly recognized the limitations of monetary measures while seeking useful alternatives.

This essay examines the unique and valuable contributions of four biological measures—life expectancy, morbidity, stature, and certain features of skeletal remains—to understand levels and changes in human well-being. People desire far more than material goods and in fact they are quite willing to trade or give up material things in return for better physical or psychological health. For most people, health is so important to their quality of life that it is useful to refer to the "biological standard of living." Biological measures may be especially valuable for historical studies and for other research circumstances where monetary measures are thin or lacking. A concluding section ruminates on the future evolution of biological approaches in measuring happiness.

Life Expectancy

The Life Table

The oldest and most widely used biological measure is life expectancy at birth. Two types of raw data are needed to construct this measure: deaths by age (also desirable are data by sex and perhaps other categories such as occupation) and a

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corresponding count of the population at risk. Vital registration (a system of recording births, deaths, and marriages as they occur) ordinarily provides the first source of information, while censuses provide the second source. Scholars have used other sources to prepare historical life tables, including parish records of baptisms and burials, continuous population registers, and genealogies. The ten-volume set *History of Actuarial Science* charts the origins and evolution of the field (Haberman and Sibbett, 1995). The concept and the data required to construct the life-expectancy measure were understood by the early 1800s, but in most countries it took many decades to form administrative structures to collect the necessary evidence: that is, the death certificates and estimates of the population at risk (Shryock and Siegel, 1975).

These data are then organized in a life table, which can take two forms: a cohort table or a period (or cross-section) table. The former is a better teaching tool to illustrate concepts. Imagine, for example, a group (cohort) of 100,000 individuals who were born in 1900 and tracked throughout their lives. It may take a century (or more) to gather the life history of the cohort, which would show the number of people alive at each precise age, say age 10.0, and the number of people who died over the ensuing year (between age 10.0 and 10.99). From this information, one can calculate probabilities of death at each age, which is the heart of the life table. Life expectancy is simply the average age at death in the cohort.

Most life tables, however, are the period variety, which imagines a synthetic or artificial cohort that experiences the age-specific death rates observed in a sample population in a single year or other short period. The probabilities of death are calculated from information on the number of deaths by age, gathered from death certificates, and the number of people alive at each age, usually estimated from census counts of the population. One calculates life expectancy at birth by supposing that an actual birth cohort experiences the age-specific mortality rates observed in a single year, say 2000. Thus a period life table provides a cross-section measure of health that will underestimate the actual life expectancy of people born in 2000 if mortality rates fall over time, as was the case in the twentieth century. The people who were old in 2000, for example, probably had higher mortality rates than the people who will be old in 2050. The actual birth cohort will live longer on average than the cross-section evidence would predict. Of course, this outcome is not inevitable because mortality rates may fluctuate over time or rise sharply during an epidemic. For example, new diseases could emerge in the next several decades, perhaps a virulent form of influenza or a new strain of HIV-AIDS, such that life expectancy is lower for the cohort born in 2000 than for the cross section observed in 2000.

Demographers have devised a number of methods to estimate life expectancy when death certificates are lacking or inadequate due to under-enumeration (United Nations, 1967). All of these methods require a way to estimate the probabilities of death by age, which are needed to compute the average length of life. If the population was closed (no migration in or out) and stationary (population size was constant), then the age distribution of the population would be constant. If the age distribution was known from a population census, one could then select a model life table—a synthesis of the age pattern of mortality and the age distribution of the population derived from the experience of many counties—that the age distribution most closely approximated. Alternatively, if census data on age are available for a sequence of years, one could calculate census survival ratios from which one could infer probabilities of death. Consider, for example, the number of people aged 40–49 who were enumerated in 1960 relative to the number of people aged 30–39 who were enumerated in 1950. The survival ratio implies a death rate that is useful if we know the population was closed, or if it was not, the death rate could be adjusted by knowledge of migration. Other methods use genealogies or family histories that record birth and deaths to estimate survival probabilities.

Some Findings from Life Expectancy Studies

The twentieth century witnessed a vast expansion in population studies that were well grounded in evidence. By the middle of the twentieth century, scholars had formulated an influential generalization called the "demographic transition" (Lee, 2003; Kirk, 1996), which depicted progress from premodern regimes of high fertility and high mortality (both in the neighborhood of 3.0 to 3.5 percent) to the postmodern situation in which both were low (about 1.0 to 1.5 percent). Typically the fertility decline preceded the fall in mortality, and depending upon the country and time period, the difference may have been several decades or longer. The process of change tended to be more rapid in the twentieth as opposed to the nineteenth century, and those transitions in the past half century occurred even more quickly.

The health side of change is often called the "mortality transition," and recent large compilations of evidence on the topic can be found in *Rising Life Expectancy: A Global History* (Maddison, 2001) and in *The World Economy: A Millennial Perspective* (Riley, 2001). Both books document and discuss possible explanations for change from the world of 1800, with one billion people and life expectancy of perhaps 25 years, to the present world of over six billion people and a life expectancy of about 66 years. By 1900, life expectancy across the world had risen slightly, to more than 30 years, but important differences existed by region, with European countries and their colonial offshoots (plus Japan) having a 20-year advantage (46 versus 26 years) over the rest of the world, which had changed little if at all. Today there is even more variation across countries, where life expectancy differs by 2:1 (ranging from about 40 years to slightly over 80 years). However, even those nations with the lowest life expectancy today are better off than the healthiest countries of two centuries ago.

As discussed below with regard to stature, biological measures and material measures of the standard of living do not always move in the same direction. For example, sub-Saharan Africa has seen gains in life expectancy over the past half century despite slow or negative economic growth, while Russia has seen higher mortality rates over the past two decades, especially among men, despite modest economic growth. Although health and material measures are often correlated positively across countries, it can be hazardous or risky to infer one in the absence of the other. It is safer to regard them as complementary as opposed to substitute measures of the standard of living.

There is little doubt that cost-effective public health measures played an important role in improving life expectancy by reducing exposure to pathogens via cleaner water, waste removal, sewage treatment, personal hygiene, and chemical control of disease vectors (Cutler, Deaton, and Lleras-Muney, 2006). More controversial are the explanations for improving health in Europe and its offshoots prior to 1900, before the public health movement flourished and before antibiotics and other advances in medical technology were available. One school of thought led by McKeown (1976) and Fogel (2004) emphasizes improving diets that stemmed from the agricultural revolution of the eighteenth and nineteenth centuries, which featured new crops and equipment as well as other changes such as enclosures, transportation improvements, and eventually the rise of free trade. Others claim that rising incomes and/or decline in the virulence of pathogens were important.

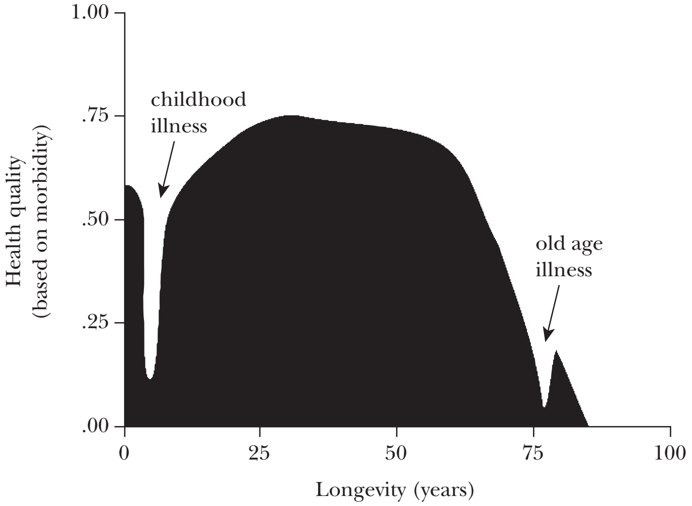
Morbidity

Adjusting Life Years for Quality of Life

Of course, life expectancy is only one dimension of health (Lilienfeld and Stolley, 1994, chap. 6). Vigor and functional capacity while alive are also important, particularly if the population is aging or if people lived under demanding conditions that led to illness or loss of functional capacity. Measuring the quality of health is challenging in part because there are numerous measures of morbidity and illness, and even if one standard is widely accepted, consistent collection of evidence over time and across space is usually difficult and expensive. The point generally holds with greater force for the past because few if any surveys are available, although the section below on skeletal remains demonstrates how bone lesions can reflect chronic morbidity conditions.

A couple of decades ago, health economists devised the concept of quality-adjusted life years (QALYs) to help estimate cost–benefit ratios from various medical treatments (Drummond, Stoddart, and Torrance, 1997). The method places a weight from 0 to 1 on the time spent in different health states. A year in perfect health is worth 1 and death is assigned a 0. There are intermediate values for states of life like living with a pacemaker implant or undergoing kidney dialysis as well as for other conditions. Some painful or agonizing states are considered worse than death and receive negative values. After considering the additional years of life created by various interventions and weighting these additional years for the quality of health, the result is a common currency that is useful for assessing the benefits of health care spending. The method has a number of practical and technical difficulties related to measuring the quality of life (assigning numerical values to morbidity), but physical examinations and surveys are ways to gain information. One popular survey asks the extent to which individuals have functional problems in five areas: mobility, pain/discomfort, self-care, anxiety/depression, and pursuit of usual activities.

Figure 1
Hypothetical Example of Morbidity and Longevity by Age



Note: A higher number corresponds to less morbidity, and 1.00 refers to complete health.

If such data were available over the entire life-span of an individual, one could construct a diagram such as the hypothetical example shown in Figure 1, which shows an individual who suffered major illnesses or morbidity early and also late in life. In this example, at no point was the person at full functional capacity or without disability (a status of 1.0). The area under the curve is a biological measure of the quality of life measured by length of life adjusted for health while living. There is obviously a tradeoff between duration and health quality that provide the same QALYs; or in terms of Figure 1, many different curves can have the same area.

Combining morbidity and length of life into quality-adjusted life years is an attractive idea, but it is difficult, time-consuming, and expensive to conduct a national census of morbidity. Thus the resource costs of measuring morbidity are high relative to constructing a life table because illnesses and disabilities are not only more common, but individual health changes over time. To score functional capacities equivalent to the life table, medical experts would regularly have to evaluate all individuals. Instead, public health officials rely on physician reports of diseases and survey information.

Data and Findings on Morbidity

In the United States, morbidity surveys began with Hagerstown, Maryland, in 1921–24 but an ongoing program did not begin until 1956. The National Center for Health Statistics interviews the noninstitutionalized population for information on doctor visits, hospital stays, acute conditions, limits on physical activity and so forth, while other surveys gain data through physical examinations and various psychological and physiological tests (Lilienfeld and Stolley, 1994, chap. 6). Numerous industrial countries such as Japan, the United Kingdom, and the Netherlands have similar surveillance systems (Alderson, 1988).

The most recent edition of *Historical Statistics of the United States* compiles dozens of morbidity statistics, including the incidence rates of many diseases. For example, immunizations led to abrupt declines in many infectious diseases in the middle of the twentieth century. Rates of measles had ranged from 250 to 750 per 100,000 people from 1912 up to about 1960, but by 1966 the rate sunk to about 20 per 100,000, or less. As another example, the average number of restricted-activity days per person shows little time trend from 1967 to 1995, based on data from the National Health Interview Survey. Of course, interview data on restricted activity may be subject to cultural norms of what constitutes sickness or disability.

Scholars have used military records to obtain a longer-term perspective on chronic conditions. Robert Fogel and Dora Costa have been leaders in organizing data collection from the Civil War pension files, which contains records of physical exams and surgeon reports that rated the capacity for manual labor. Between the early 1900s and the 1970s chronic disease rates fell markedly, notably by two-thirds for respiratory problems, heart disease, and joint and back problems (Costa, 2000). Shifts to less physically demanding occupations explain nearly one-third of the decline, and a lower prevalence of infectious diseases accounted for nearly one-fifth of the decline. Interestingly, the duration of chronic conditions was unchanged, but if measured by performance (difficulty walking, for example) men were less disabled.

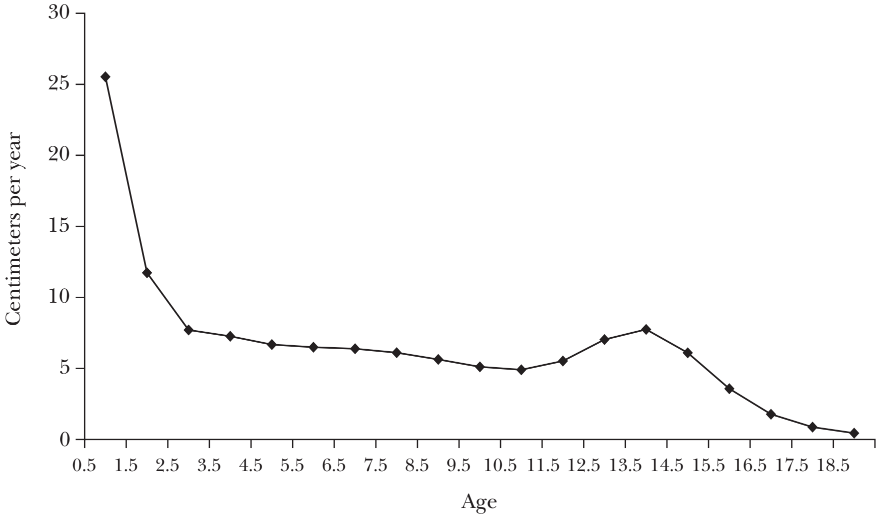
Stature

Stature and Nutritional Status

J. M. Tanner's (1981) authoritative book *A History of the Study of Human Growth* recounts the long history of studying body size and proportions. Artists were among the first to study human form quantitatively for purposes of accurately rendering sculptures and paintings. What might be called scientific interest in heights began during the Enlightenment. Early studies of auxology—that is, the study of human growth—were sporadic and imprecise attempts made by individuals. However, while systematic data on both national income and life expectancy awaited large-scale government action, useful measurements of height and related attributes could be made on a small scale. Thus, auxology made important progress before the end of the nineteenth century.

The greatest strides in the modern study of human growth occurred in the late 1800s and early 1900s with the work of Charles Roberts, Henry Bowditch, and especially Franz Boas. Roberts's work in the 1870s increased the sophistication of judging fitness for factory employment with the use of frequency distributions of stature and other measurements, such as weight-for-height and chest circumference. Bowditch assembled longitudinal data on stature to establish the prominent gender differences in growth. In 1875, he supervised the collection and analysis of

Figure 2
Growth Velocity of Well-Nourished Boys



Source: The National Health and Nutrition Examination Survey (Centers for Disease Control and Prevention, 2000).

heights from Boston school children, a data set on which he later used Galton's method of percentiles to create growth standards. In a career that spanned several decades, Boas identified salient relationships between the tempo of growth and height distributions and in 1891 coordinated a national growth study, which he used to develop national standards for height and weight. His later work pioneered the used of statistical methods in analyzing anthropometric measurements and investigated the effects of environment and heredity on growth. The results of an explosion of growth studies in the twentieth century are contained in *Worldwide Variation in Human Growth* (Eveleth and Tanner, [1976] 1990).

Figure 2 displays the growth velocity of well-nourished boys taken from the National Health and Nutrition Examination Survey (NHANES) survey (Centers for Disease Control and Prevention, 2000). While infants grow rapidly, the rate declines during childhood and reaches a preadolescent minimum around age 11. Nutritional requirements increase substantially during the subsequent adolescent growth spurt. Although the adolescent spurt is somewhat larger for boys, they end up 4.5 to 5.0 inches taller primarily because the boys have two additional years of growth at preadolescent rates. Several studies confirm the similarity of this pattern across a wide range of well-nourished ethnic groups; children who grow up under good conditions are approximately the same height regardless of ethnic heritage (see Steckel, 1995, for additional discussion and references).

Numerous studies establish the importance of diet, exposure to disease, and physical activity or work for the growth of children (Bogin, 2001; Eveleth and Tanner, [1976] 1990; Tanner, 1978). In this context, it is useful to think of the body as a biological machine that operates on food as fuel, which it expends in moderate amounts while idle (resting in bed) but in larger quantities while working or fighting infection. During World War II, for example, children's heights floundered in Russia and the Netherlands under restricted food intake. Disease may also stunt growth because it can divert nutritional intake to fight infection or result in incomplete absorption of what is consumed. Similarly, physical activity or work places a claim on the diet. For these reasons, average adult height reflects a population's history of *net* nutrition.

If better times follow a period of deprivation, a person's growth may exceed that ordinarily found under good conditions. Catch-up (or compensatory) growth is an adaptive biological mechanism that complicates the study of child health using adult height, because it can partially or completely erase the effects of deprivation. Between birth and maturity, a person could potentially undergo several episodes of deprivation and recovery, thereby obscuring important fluctuations in the quality of life.

Preferably, researchers would have the complete growth history available for study, like the curve depicted in Figure 2. Even these data would be inadequate for a thorough understanding adult height, however, because diet, disease, and physical activity may trade off in combinations that affect growth at each age. Though very useful for analysis, velocity at each age provides only proximate knowledge of why average adult height takes on the value it does (or did). Thus, a complete understanding requires dozens of pieces of information, and even more if components of diet and varieties of disease are viewed separately. In sum, average height offers a good measure of welfare or the quality of life during childhood, but it can be difficult to analyze or explain because it reflects or captures many conditions over the period of growth.

Comparing Stature, Life Expectancy, and GDP

Income is a potent determinant of stature that operates through diet, disease, and work intensity, but analysis of the determinants of stature must also recognize other factors. Personal hygiene, public health measures, and the disease environment affect illness; and work intensity is a function of technology, culture, and methods of labor organization. In addition, the relative price of food, cultural values such as the pattern of food distribution within the family, methods of preparation, and tastes and preferences for foods may also be relevant for net nutrition. While influential policymakers often view higher incomes for the poor as the most effective means of alleviating protein-energy malnutrition in developing countries (World Bank, 1993), development economists have debated the effects of income on the diets of the poor (Behrman and Deolalikar, 1987). Extremely poor families may spend two-thirds or more of their income on food, but even a large share of their very low incomes purchases few calories. Malnutrition associated with extreme poverty has a major impact on height. But expenditures beyond those needed to satisfy calorie requirements purchase largely variety, palatability, and convenience.

Impoverished families can afford little medical care, and additional income improves health through control of infectious diseases. Although tropical climates have a bad reputation for diseases, King (1966) argues that poor health in developing countries is largely a consequence of poverty rather than climate. A group of diseases are spread by vectors that need a warm climate, but poverty is responsible for the lack of doctors, nurses, drugs, and equipment to combat these and other diseases. Poverty, via malnutrition, increases the susceptibility to disease.

Gains in stature associated with higher income are not limited to developing countries. Within industrialized countries, height rises with socioeconomic class (Eveleth and Tanner, 1976, p. 34). These differences in height are related to improvements in the diet, reductions in physical work loads, and better health care. Expenditures on health services rise with income, and there is a positive relationship between health services and health (Fuchs, 1972).

At the individual level, extreme poverty results in malnutrition, retarded growth, and stunting. Higher incomes enable individuals to purchase a better diet and, correspondingly, height increases; but once income is sufficient to satisfy caloric requirements, only modest increases are attainable through change in the diet. Height may continue to rise with income because individuals purchase more or better housing and medical care. As income increases, consumption patterns change and a larger share of genetic potential is realized, but environmental variables are powerless after attaining the capacity for growth.[1] The limits to the process are clear from the fact that people who grew up in very wealthy families are not physical giants.

If the relationship between height and income is nonlinear at the individual level, then the relationship at the aggregate level depends upon the distribution of income. Average height may differ for a given per capita income depending upon the fraction of people with insufficient income to purchase an adequate diet or afford medical care. Because the gain in height at the individual level increases at a decreasing rate as a function of income, one would expect, for a given per capita income, that average height at the aggregate level would rise with the degree of equality in the income distribution (assuming there are people who have not reached their genetic potential).[2] Therefore one should be cautious in estimating and interpreting the relationship between per capita income and average height at the aggregate level.

The aggregate relationship between height and income can be explored by matching the results of 18 national height studies tabulated in Eveleth and Tanner ([1976] 1990) with per capita income data compiled by Summers and Heston (1991). Despite the large number of factors that may influence the relationship, Figure 3 shows a high correlation (about 0.82) between average height in a country

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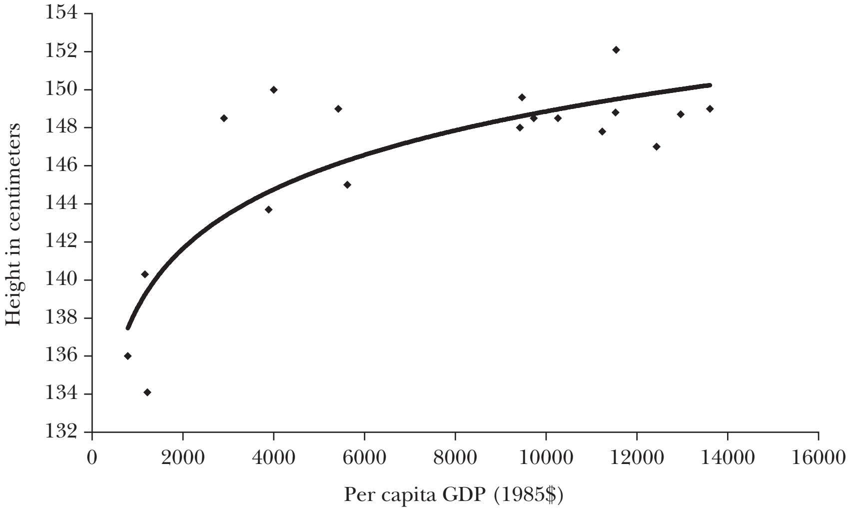
[1] Of course, it is possible that higher incomes could purchase products such as alcohol, tobacco, or drugs that impair health.

[2] This argument is reasonable over the range of data used in the empirical analysis discussed below. However, within an extremely poor country, it might be possible for average height to increase with an increase in inequality if the rich did not approximately attain their genetic potential.

Figure 3
Real per Capita GDP and Average Height at Age 12 of Boys



Source: Calculated from data in Eveleth and Tanner ([1976] 1990) and from the Penn World Tables.

and the log of per capita income.[3] Although the figure illustrates the case for twelve-year-old boys, a similar relationship holds for girls and for adults. The figure makes clear that income has diminishing returns on average height. Once basic necessities are satisfied, higher income has less impact on health and physical growth. Thus, stature is good measure of deprivation but not opulence. One should be wary of estimating GDP from height because the curve displayed in Figure 3 is a function of health technology and the disease environment. Over time the curve has shifted upward, receiving for example, a large boost with the rise of the germ theory of disease, which led to several cost-effective innovations such as water purification.

Figure 4 uses the same 18 height studies to display a relationship between life expectancy at birth and average height (for boys aged 12). In this case, the relationship is approximately linear, at least over the range of data available. This makes sense because average height and life expectancy are both measures of health, indeed opposite sides of the same coin. When children are sick their growth suffers and they die at high rates. Moreover, there seems to be an upper limit to both life expectancy and average height (or at least limits that rise slowly). In

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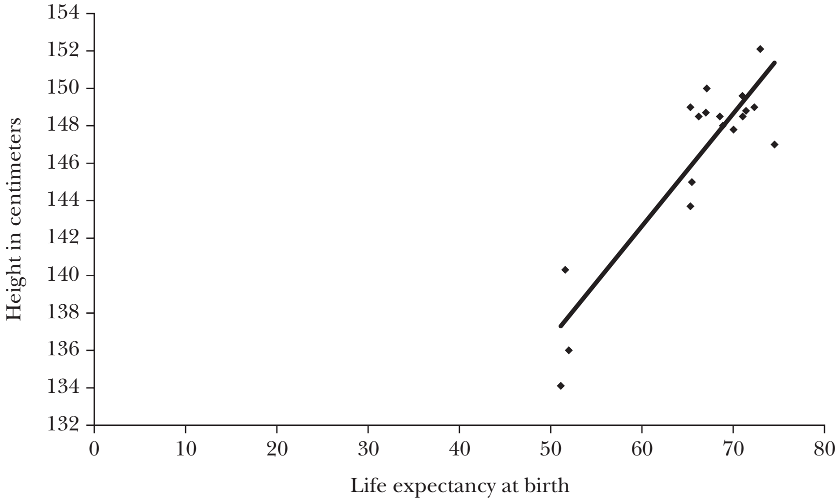
[3] Results in this section extend my earlier work (Steckel, 1983) by including additional height studies from Eveleth and Tanner (1990) and income data from the Penn World Tables (Summers and Heston, 1991). Functional form was explored by regressing average height on various nonlinear relations in per capita income and the log of per capita income. Fit improved substantially by going from the linear to the quadratic formulation but only slightly by going from the quadratic to the cubic. Because the semi-log form fits about as well as the cubic but is simpler, results are reported for the semi-log formulation.

Figure 4
Life Expectancy at Birth and Height of Boys at Age 12



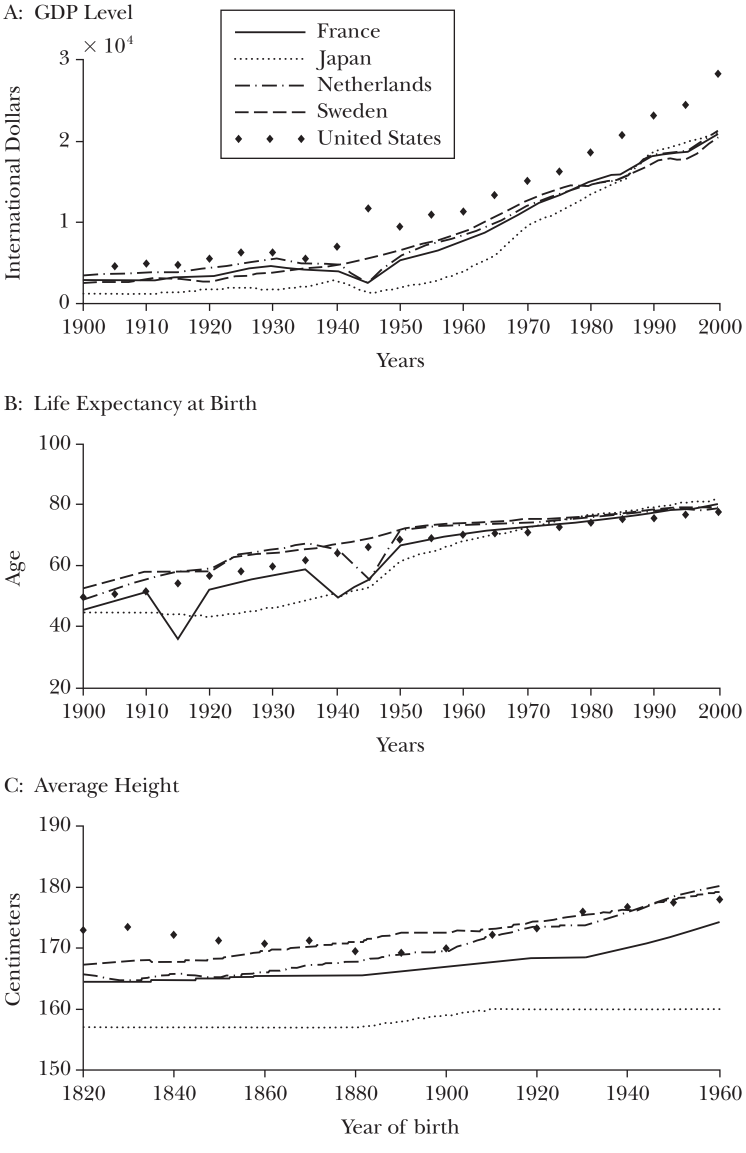
Source: Calculated from data in Eveleth and Tanner ([1976] 1990) and from the World Bank *World Development Report* (various years).

contrast the relationship between height and GDP is nonlinear. (If this relationship *were* linear, imagine how tall Bill Gates's children would be!) Many nations have become richer over time, but their gains in health have not kept pace in recent decades—which is another way of saying that income has reached diminishing returns for health. Figure 5 confirms the pattern for five countries: France, Japan, the Netherlands, Sweden, and the United States. All series increased, but the gain in GDP was far larger than the biological measures during the twentieth century.

Recent Findings on Stature

Regional and national data series exist for heights, but historians have constructed such data using information originally collected for other purposes. In the past 15 years, scholars have completed several large historical studies or compilations of evidence on height motivated by an interest in understanding the standard of living. The potential data sources include slave manifests, muster rolls, convict records, passport applications, and so forth. The most abundant source is military organizations near the middle of the eighteenth century, which routinely recorded heights for identification purposes, to assess fighting strength, and to make uniforms. Among the country studies are those of Austria-Hungry, England, and Japan (Floud, Wachter, and Gregory, 1990; Komlos, 1989; Mosk, 1996). Roderick Floud and I organized a large effort for comparative study of England, France, the Netherlands, Sweden, Germany, the United States, Australia, and Japan (Steckel and Floud, 1997). Komlos edited papers compiling evidence for numerous countries around the globe (Komlos, 1994, 1995), and I surveyed the state of the field as of the mid-1990s (Steckel, 1995). Thus, historical perspective is available for

Figure 5
Real GDP per Capita, Life Expectancy, and Average Height in Five Countries

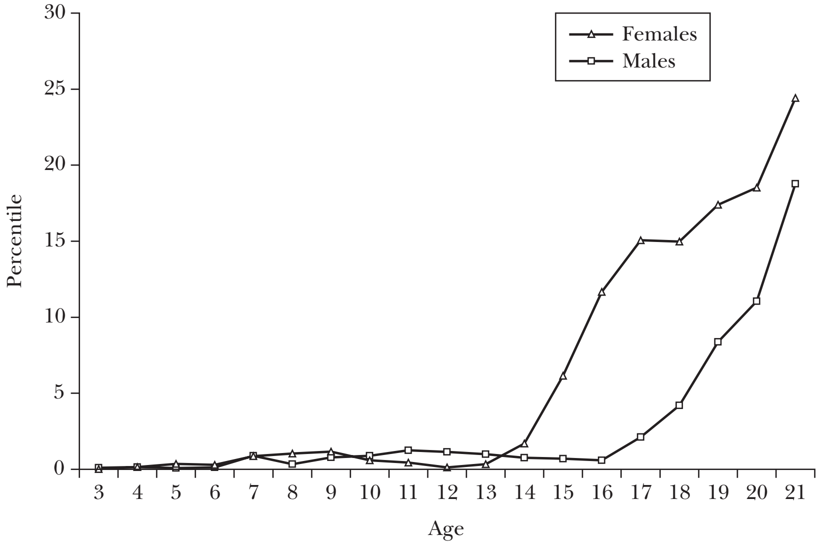


Sources: Penn World Tables; Costa and Steckel (1997); Drukker and Tassenaar, (1997); Honda (1997); Sandberg and Steckel (1997); Weir (1997).
Note: International dollars are "Geary-Kahmis dollars," a measure based on purchasing power parities of currencies and the international average prices of commodities in dollars.

numerous countries. Moreover, the World Bank, the United Nations, and other agencies now regularly collect height data as part of occasional surveillance programs, to evaluate interventions, and to investigate socioeconomic mechanisms that affect physical growth and child health.

Figure 6

Percentiles of Modern Height Standards Reached by American Slaves from Cotton States



Source: Calculated from slave manifests and Steckel (2007).

Collectively, the existing studies about stature both confirm and contradict certain long-held beliefs about differences and changes in human well-being. Heights substantiate the poor health of cities relative to rural areas prior to 1900, a pattern long known from historical population studies. In nineteenth century Sweden, for example, average height was three to eight centimeters greater in rural areas compared with Stockholm, depending upon the time period and rural area (Sandberg and Steckel, 1988).

American Slaves. Anthropometric history has uncovered some surprising patterns that have challenged traditional interpretations of the past and sometimes provided new insights for human biology. One example is the extraordinarily depressed growth in American slave children and their substantial recovery as teenagers, as shown in Figure 6, which is based on the heights of approximately 48,000 individuals exported from the cotton states. The children were among the smallest ever measured and would have caused alarm in any modern pediatrician's office. Yet the adults were comparable in height to the contemporary nobility of Europe, about half an inch shorter than Union Army troops, and less than two inches below modern height standards (average for males and females). Children adopted from low-income into high-income countries also show substantial catch-up growth, again showing that the pattern is biologically possible. Selectivity cannot explain the pattern, because the heights of slaves shipped by traders were no different from those transported by plantation owners, and higher death rates for shorter individuals would explain at most a trivial portion of the accelerated growth of the teenagers (Steckel, 2007).

The extent of deprivation and catch-up was extraordinary and unprecedented in historical or modern populations, which suggests that slavery was somehow responsible. All height studies, whether for the past or the present, show that the height percentiles attained by children and by adults were similar within the same population or community.

The health deficits of young slaves probably began with low birth weights (associated with seasonal rhythms in the diet, work, and illness of pregnant slaves) and were accentuated by attenuated breastfeeding and low-protein diets until the slave children began working around age ten (Steckel, 1986a,b, 1987). Nonworking slaves were fed little meat, a result commonly achieved through dietary segregation of food prepared in central kitchens whereby children and adults usually ate at separate times and places, with children in the nursery and working adults in the fields. If rations were allocated to families, then owners placed strict limits on the amount of meat given to slaves who did not work in the fields. Owners discovered their workers could not perform hard labor without meat in their diet, which implies that parents potentially paid a heavy price for sluggish field work (possibly a whipping) if they shared much of the meat rations with their children. Such feeding practices no doubt severely strained the family as a unit able to protect and nurture children.

Remarkably, this pattern of deprivation and catch-up was potentially profitable for slave owners. Dietary studies show that protein is essential for growth. Meat rations for the working slaves and protein deficits estimated for poor children in developing countries suggest that the protein deficit was 50 percent or more. Assuming a protein deficit was the only obstacle to achieving modern height standards, one can calculate a rate of return on feeding children enough meat protein to reach these standards. The calculation is based on the protein content and price of pork, as well as the knowledge that slave values increased by 1.37 percent per inch of height. The rate of return for a diet adequate to reach modern health standards is actually negative if the deficits were as high as 50 percent, and the rate of return remains under 1 percent even when one presumes that mortality rates would have fallen in half from better nutrition. Rates of return would have been even lower if well-nourished children were highly active and required more supervision, or if there was a “leaky nutritional bucket”—that is, if children had parasites, malaria, and other diseases that would have diverted or absorbed some of the better nutrition. It is well-established that poor nutrition in early childhood permanently reduces cognitive ability, which could have limited the capacity of former slaves to compete in the economy following emancipation. It may seem paradoxical, but planters who owned all future labor would have found that poor nutrition for young children was profitable.

Inequality. Comparing height patterns with traditional monetary measures of social performance across developing and developed countries in the second half of the twentieth century revealed a useful role for heights: assessing biological inequality. In Steckel (1983), I found that average height was not only a logarithmic function of average income at the national level, but that holding income constant, average height increased as the degree of income inequality declined. From this

Figure 7
Heights of Native-born American Men and Women by Year of Birth

Source: Steckel (2006, p. 2-503).
Note: Prior to the twentieth century, the sample is composed of whites and disproportionately of northerners. The heights in the middle of the nineteenth century are based on interpolations from the Ohio National Guard.

insight, researchers began to study occupational and regional differences in stature as a proxy for inequality. In late eighteenth-century England, for example, the average heights at age 14 of poor boys admitted to the Marine Society were 20 centimeters below those of upper-class boys who attended the elite academy at Sandhurst (Floud, Wachter, and Gregory, 1990). During the same era, the difference in average height between the rich and the poor in the United States was roughly 3 centimeters (Margo and Steckel, 1982).

Time Trends in Average Height. Economic historians were surprised to find that heights in America declined during the middle of the nineteenth century (Figure 7), which occurred during the midst of an industrial revolution and rapid economic growth. The United States and England were two countries to have experienced substantial and sustained height declines during industrialization prior to the close of nineteenth century (Steckel and Floud, 1997).[4] Thus, height and per capita income are not always positively correlated in longitudinal data, and the concept of net nutrition helps organize thoughts for an explanation. Material living

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[4] Heights in several European countries declined during the late 1830s and the 1840s in connection with harvest failures and/or rising food prices. By the end of the nineteenth century, the public health movement noticeably diminished the consequences of industrialization in terms of health events.

standards were rising rapidly, but gross nutrition was either declining for a substantial segment of the population or demands on their food intake were rising, or both.

Numerous explanations for the American case are now under investigation. Rising food prices, growing inequality, and the Civil War (which interrupted food production) could have lowered gross nutrition, while the spread of diseases made greater claims on the diet (diseases might have spread via urbanization and the growth of interregional trade, and the rise of public schools that brought more children and pathogens together) (Komlos, 1998; Steckel, 1995).

The average height of Americans has leveled off in recent decades, while that of Europeans continues to grow. The Dutch are now the tallest, with the men averaging around six feet while Americans fall some two inches below. Average heights in northern Europe now exceed those in the United States, but explanations have been difficult to quantify and evaluate. Some people point to differences in the health care system, which is heavily subsidized and widely provided or universal in northern Europe as opposed to the United States. Inequality could play a role, with democratic socialism leveling disposable incomes and raising average heights relative to the United States. Perhaps diets are the culprit, whereby Americans eat more fast food and snacks that crowd out fruits and vegetables, which provide micronutrients.

Equestrian Plains Nomads. With the possible exception of slaves, no group in American history has suffered greater misunderstanding and manipulation than Native Americans. In the eyes of many Euro-Americans of the mid-nineteenth century, the Native Americans only terrorized settlers and stole horses. Near the turn of the century they became entertainers and caricatures in the public imagination, as illustrated by Buffalo Bill's Wild West shows. The *Saturday Evening Post* then serialized romantic stories of the old West, which were followed by western movies, in which Indians were usually the bad guys. By the 1960s, Native Americans were often portrayed as victims and by the 1990s as ecologically sensitive caretakers of the land. It is difficult to sort fact from fiction in this montage of images.

However, height data provide some facts about nutritional status and health-quality of life. Euro-Americans were not the tallest population in the world, at least in the middle of the nineteenth century. This honor went to Native Americans who used horses to hunt and migrate across the Great Plains (Steckel and Prince, 2001). According to data originally collected by Franz Boas, the men in eight of these tribes averaged 172.6 centimeters ($N = 1{,}123$), the Cheyenne topped the list at 176.7 ($n = 29$), and the Arapaho were second at 174.3 ($N = 57$). The average heights follow an inverted U-shape with respect to latitude, as they are arranged in Table 1. The shortest tribes occupied the northern (Assiniboin) and the southern plains (Comanche), while the Arapahoe and the Cheyenne of Colorado and Wyoming were the tallest. The height achievement of Native Americans is all the more remarkable because the tribes suffered repeated bouts of smallpox and other epidemic diseases that substantially reduced their numbers. Various wars or conflicts among tribes and with Euro-Americans also disrupted food production or otherwise diverted resources that could have improved the diet. It is unlikely the

Table 1

Average Height of Equestrian Plains Nomads in the Mid-Nineteenth Century

Tribes (arranged by latitude, from north to south)	*All adult men*		
	Height (cm)	*Standard deviation*	*N*
Assiniboin	169.6	6.0	22
Blackfeet	172.0	5.3	58
Crow	173.6	6.7	227
Sioux	172.8	5.6	584
Arapaho	174.3	6.9	57
Cheyenne	176.7	5.6	29
Kiowa	170.4	5.7	73
Comanche	168.0	6.4	73
Total Sample	**172.6**	**6.2**	**1,123**

Source: Steckel and Prince (2001).

Plains tribes were tall due to selective editing or removal of short people by disease. They were tall prior to the epidemics of the 1830s, and the selective effect of mortality on average height is quite small.

Several ecological and socioeconomic variables explain much of the height differences. The tribes were taller if they lived in environments with more green vegetation (a source of food for people and animals); did not live close to the major trails leading to the West, which were centers for the spread of diseases and conflict (specifically the Santa Fe and Oregon trails); and had smaller land areas per capita, an effect possibly driven by the costs of policing or defending territory. Boas was able to estimate the birth year of each person, which could be linked with conditions during the growing years. Higher rainfall during the growing years (estimated from tree rings) promoted plant growth and the supply of food that increased adult height. On the other hand, epidemics as assessed from historical accounts had no effect on height; and surprisingly, the initial transition to reservations was beneficial for growth (though reservation living was unhealthy near the turn of the century).

Skeletal Remains

It is unfortunate that Tanner's (1981) imposing book on the intellectual history of height research has not been duplicated in other fields such as physical anthropology, which examines bone lesions and dimensions in skeletal remains for insights into nutrition, disease, trauma, and activity patterns.[5] According to Moodie (1923, p. 21), whose book provides an excellent summary of the field up to the early 1920s, the term "paleopathology," a branch of physical anthropology that studies

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[5] See, however, a collection of papers recently published on the history of bioarchaeology (Buikstra and Beck, 2006).

skeletal lesions, was first defined in *A Standard Dictionary of the English Language*, published in New York in 1895. The science stems from John M. Clark's studies of pathological conditions among invertebrate fossils at the State Museum in Albany, New York. In 1913, Sir Marc Armand Ruffer introduced the term to the medical literature in his research on Egyptian mummies.

Evidence from skeletons vastly extends the reach of anthropometric history by depicting aspects of well-being over the millennia, from hunter-gatherers to settled agriculture and through the rise of cities, global exploration and colonization, and industrialization. Skeletons are widely available for study in many parts of the globe. A group of skeletons can provide age- and source-specific detail on nutrition and biological stress from early childhood through old age; indeed, several indicators of health during childhood are typically measurable from the skeletons of adults. Skeleton 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. The value of skeletons is substantially enhanced when combined with contextual information from archaeology, historical documents, climate history, and geography.

Bones are living tissues that receive blood and adapt to mechanical and physiological stress. If a bone is injured by trauma, infection, or erosion of cartilage such that joint surfaces deteriorate, a scar forms and leaves a mark that is usually permanent or at least identifiable if the person dies many years later (Larsen, 1997). More generally, the skeleton is an incomplete but useful repository of an individual's history of health and biological stress that often takes the form of chronic morbidity. Physical anthropologists have learned that bones can be used to estimate stature and that various lesions such as tooth enamel deformities reflect poor health in early childhood. Other lesions on the skull reveal iron deficiencies in early childhood, and serious skeletal infections leave permanent marks on a bone's surface. The front of the tibia is particularly vulnerable in this regard because it has little soft tissue for protection, and even small injuries are compounded by dietary deficiencies such as lack of vitamin C. Trauma is readily identified by bone misalignment, skull indentations, or weapon wounds. Degenerative joint disease, caries, and abscesses are signs of aging.

Long-Term Evidence from Skeleton Studies

Scholars have completed few large-scale comparative studies of community health using skeletal data. The field is relatively new, and building up a database by analyzing skeletons one at a time is highly time consuming. In addition, the variables collected by physical anthropologists and the details of measurement tend to vary across sites and schools of thought, so meta-analysis based on evidence from past published studies is generally not an option.

The Backbone of History: Health and Nutrition in the Western Hemisphere is the largest comparative skeletal study undertaken to date. It sought to study not only the Neolithic Revolution (a transition from hunting and gathering to agriculture), but health across a broad swath of time, space, and ethnic groups (Steckel and Rose, 2002a). After agreeing on a coding scheme, collaborators, including myself, pooled evidence on seven skeletal features from 12,520 remains found at 65 localities that were collectively inhabited from 4000 BCE to the early 1900s. We distilled the skeletal evidence into a health index, discussed in more detail below, that theoretically could range from zero (most severe expression in all categories) to 100 (complete absence of lesions or signs of deficiency for every individual at the locality). In practice, this index averaged 72.8 (s.d. = 8.0) and varied from 53.5 to 91.8 (Steckel, Sciulli, and Rose, 2002). Surprisingly, in comparing archeological sites, we find that Native American populations were ranked among the most and least healthy populations, with European Americans and African Americans (slaves excepted) falling near the middle of the distribution.

At this stage of research on skeletons, numerous simplifying assumptions and approximations are required to distill diverse skeletal data into a single number for comparative ranking and study of populations.[6] Unfortunately, many sites covered in *The Backbone of History* lack reliable estimates of life expectancy. However, a positive correlation between morbidity and mortality is likely, which mitigates the lack of data on life expectancy in ranking health across sites.

The health 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 (Steckel, Sciulli, and Rose, 2002). For each individual, the seven skeletal measures discussed above (including stature) were graded on a scale of 0 (most severe expression) to 100 (no lesion or deficiency). Age-specific rates of morbidity pertaining to the health indicators during childhood (stature, linear enamel defects, and anemia) were calculated by assuming that conditions persisted from birth to death, an assumption justified by knowledge that childhood deprivation is correlated with adverse health as an adult.[7] The duration of morbidity prior to death is unknown for the infections, trauma, degenerative joint disease, and dental decay (and will be the subject of future research), but was approximated by an assumption of 10 years. Results are grouped into age categories of 0–4, 5–9, 10–14, 15–24, 25–34, 35–44, and 45+. Next, the age-specific rates for each skeletal measure were weighted by the relative number of person-years lived in a reference population that is believed to roughly agree with pre-Columbian mortality conditions in the Western Hemisphere (Model West, level 4), and the results were multiplied by life expectancy in the reference population (26.4 years) and expressed as a percent of the maximum attainable health. The seven components of the index were then weighted equally to obtain the overall index. Of course, numerous assumptions underlying the index can be challenged, modified, and refined. In particular, conditions like dental decay and trauma probably have different effects depending on the social safety net, common production technology, medical technology, and other factors that vary in

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[6] 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] One theory outlining the importance of fetal and early childhood health for adult health is the "Barker hypothesis" (Barker, 1994, 1998). For a general discussion see Fogel and Costa (1997, pp. 56–7).

unknown ways across societies. In addition, the index is an additive measure that ignores interactions.

The most intriguing finding from this project was a long-term decline in the health index in pre-Columbian America. The downward trend over time is shown in Figure 8.[8] On average, the health index fell by 0.0025 points per year from roughly 7500 years ago to about 450 years ago, which amounts to 17.5 points over seven millennia. A decline of this magnitude represents a significant deterioration in health; it is larger than the difference between the most and least healthy groups who lived in the Western Hemisphere.

These observations are concentrated in the two millennia before the arrival of Columbus, when there was clearly a great deal of diversity in health across sites. The highest value for the index did occur at the oldest site, but two sites in the later era also scored above 80. The least healthy sites (scores under 65) were all concentrated within 2000 years of the present.

In Steckel and Rose (2002b), my coauthor and I estimated a sequence of regressions that examined the statistical connection between health and various ecological categories like climate, size of settlement, diet, terrain, and vegetation. Climate—as measured in categories of tropical, subtropical, and temperate—bore no relevance to the health index. This result was unanticipated and bears further study with more refined measures. Living in a larger community was deleterious to health. Groups living in paramount towns or urban settings had a health index nearly 15 points (two standard deviations) below that expressed for mobile hunter-gatherers and others not living in large, permanent communities. Of course, large pre-modern communities faced unsanitary conditions conducive to the spread of infectious disease and other maladies. Diet was also closely related to the change in the health index, with performance being nearly 12 points lower for those subsisting mainly on the triad of corn, beans, and squash, compared with the more diverse diet of hunter-gatherer groups. Because the transition to settled agriculture usually occurred with the rise of large communities, it is difficult to separate their effects on health.

Higher elevations reduced health: people who lived above 300 meters scored about 15 points lower in the index. The exact mechanism for this relationship is unknown, but it is likely that a richer array of foods was available (with less work effort) at lower elevations. Vegetation surrounding the site may have affected health via the type and availability of resources for food and shelter. Forests for example, provide 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. Those living in forests and semi-deserts had a health index about nine points higher than inhabitants of open

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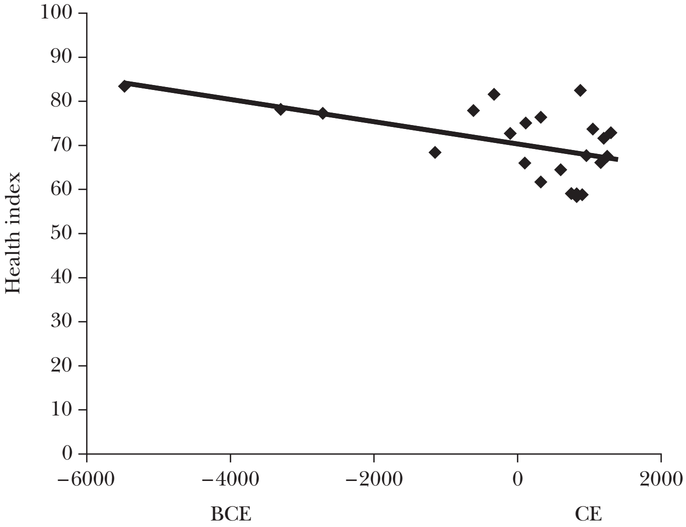
[8] This estimated linear regression equation is: $HI = 65.41 + 0.0025\ YBP$, where *HI* stands for the health index, and *YBP* represents years before present (before 1950). There were 23 pre-Columbian sites in America in our sample, and the R^2 of the regression is 0.53. The *t*-value on the coefficient of the time variable is 2.89.

Figure 8
Pre-Columbian Time Trend in the Health Index



Source: Steckel and Rose (2002b, p. 565).

forests and grasslands. Flood-plain or coastal living provided easy access to aquatic sources of food and enabled trade compared with more remote, interior areas, but trade 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. Apparently the net benefit to health favored coastal areas, where the health index was about 8 points higher compared with noncoastal regions.

Breaking the sample into two chronological periods greater than or less than 1500 years before the present, it seems that people increasingly lived in less healthy ecological environments. One possible explanation is that population growth may have led to resource depletion that forced migration into less desirable areas, where greater work effort was required to provide food. Another possibility is that over time, more complex, hierarchical societies emerged, leading to greater biological inequality. In Steckel and Wallis (2007), my coauthor and I consider why people would choose to move to larger settlements that were less healthy, and we note that trauma in the early cities was less than one-quarter that found among hunter-gatherers. We connect the control of violence with the rise of the “natural state,” which was essentially a set of credible agreements among powerbrokers to “wage peace” and capture the economic benefits of cooperation.

Frontiers for Measurement of Human Well-Being

For over three centuries, scholars have struggled to measure and analyze personal and national well-being. The subject is complicated, and despite great leaps forward, much remains to be understood. Although some overlap exists, the customary measures of human well-being used by social scientists may be classified into three broad categories: material, psychological, and health.

Over the past century, researchers have made considerable progress in defining and implementing monetary measures such as GDP. Although research continues to expand on monetary measures, the pace has slowed relative to the high point of the mid-twentieth century and has reached diminishing returns in adding new useful information. There has been a recent resurgence of interest in measuring well-being through survey techniques that ask about "happiness" (for an example in this journal, see Kahneman and Krueger, 2006). But nagging questions remain about whether people's evaluations of what they report as their "happiness" mean the same thing in one country or era as another. At least so far, psychologists have not come forward with new approaches to the measurement of well-being that have captured the general approval of social scientists.

This essay has focused on biological measures of well-being, where great progress has been made in measurements of life expectancy, morbidity, and nutritional status. In my view, the next great research frontier will use nano-size biosensors to measure brain activity and assay biochemicals in a search for patterns and determinants of well-being and happiness. For example, miniature total analysis systems, commonly called lab-on-a-chip devices, contain all the necessary elements for analyzing miniscule amounts of bodily fluids, including the intake, transport, mixing, and separation of fluids and the measurement of results (Focus, 2006; Whitesides, 2006). Nanotechnology presents legitimate risks and concerns, and the public must be educated to judge the benefits and costs, and if necessary, be prepared to regulate intelligently the development of these remarkable devices. However, nanosensory systems do offer the possibility of vastly improved measures of morbidity. Various concentrations of proteins or other chemicals in the blood may signal high stress levels, increased risk of heart attack, various cancers, epileptic seizure, or inflammation in specific organs. One could ultimately imagine monthly or even daily reports on a country's state of health much like we receive on per capita income or jobs, but based on information gathered by and uploaded from nano-scale devices imbedded in the bodies of a national sample of individuals.

The historical pioneers in the measurement of human well-being have been economists on the monetary measures; human biologists and economists on stature and nutritional status; psychologists on the happiness surveys and brain chemistry; and demographers on issues of life expectancy. Anthropologists, economists, human biologists, medical specialists, historians, and others have also begun to examine these issues in studies of skeletons. The disciplinary boundaries are blurring as researchers increasingly seek and recognize the interrelationships among these traditionally distinct ways of thinking about human well-being.

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