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Review

Height, Body Size and Longevity

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Life expectancy, mortality and longevity data related to height and body size for various US and world population samples are reviewed. Research on energy restriction, smaller body size and longevity is also examined. Information sources include various medical and scientific journals, books and personal communications with researchers. Additional information is presented based on research involving eight populations of the world noted for their health, vigor and longevity. This information includes the findings of one of the authors who led research teams to study these populations. While conflicting findings exist on the cardiovascular death rates for shorter people, many examples of short populations with very little heart disease are described. Most cancer studies indicate that shorter people have significantly lower mortality risk. Considerable data suggest that shorter people generally have greater longevity than taller people, and extensive animal research supports human longevity findings. Tall populations with low mortality rates are also described. Shorter stature and smaller body weight appear to promote better health and longevity in the absence of malnutrition and infectious diseases. Several theoretical reasons for this greater longevity potential are covered. Also discussed, is the role of socioeconomic status, diet, relative weight, environment and other factors in increasing or decreasing the longevity of individuals, regardless of their heights and weights.

Key words: body height, body size, health, longevity, nutrition

Human body size in the Western world has been increasing for about 100 to 150 years. During this century, a growth rate of about 2.54 cm per generation has been experienced. Greater body weight due to added muscle, bone and fat mass has also accompanied this increase in height. Along with increasing body size, we have seen a great increase in life expectancy due to improved living standards and sharply reduced malnutrition and communicable diseases. In addition, improved farming and distribution techniques have provided an overabundance of energy-rich food which appears to have promoted the modern increase in body size and chronic diseases (1-3).

Most medical practitioners have assumed that increasing height is related to better nutrition and medical care, and many believe that we should feed children so that they achieve their maximum genetic potential for height. However, some scientists doubt the wisdom of promoting maximum growth and development in our children because it fosters the early development of chronic diseases and shortens longevity. The health risks of increasing stature and body size were identified over 20 years ago by Stini (1) and Samaras (4). Walker *et al.* (5) also questioned this policy, and Kaplan and Toshima (6) stated: "Tallness is not necessarily an indicator of health or a healthier lifestyle. Height may even be an indicator of over nutrition, which in turn creates risk for poor outcomes later in life."

This review was conducted to determine whether there is evidence to support the concerns of these scientists. Contrary to conventional beliefs, much evidence was found suggesting that shorter stature and smaller human body size are less susceptible to chronic diseases and tend

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to have greater longevity. This evidence includes life expectancy, mortality and longevity data from various groups in the US and other countries. Animal experiments and findings also provide extensive data showing that energy restriction and smaller body size provide superior health and longevity. However, several other factors also have a strong influence on mortality and longevity. These include socioeconomic status, medical care, stress, nutrition, exercise and smoking (7).

This paper is a previously unpublished overview of findings relating human height and body weight to health and longevity. Contrary to epidemiological studies showing that short people are more likely to suffer from coronary heart disease (CHD), substantial data were found showing that many short population groups have the lowest CHD death rates in the world. Awareness of these findings is important to the medical community because they challenge the widely held belief that promoting maximum growth and development of our children is a desirable health objective. This paper also provides a baseline for reevaluating our present viewpoint and for future research to determine the optimum height and weight of humans.

While this paper is primarily focused on lesser known research showing that shorter people have better health and greater longevity, a number of studies have reported that tall people are healthier and these are reviewed first.

Review of Findings

Overview of the Lower Mortality Rate of Taller People

Waaler (8) conducted a 16-year study of 1.8 million Norwegians and found that tall people had a 15 % lower death rate than short ones. However, men exceeding 187 cm generally had an increasing rate. The study involved 176,574 people who died between 1963 and 1979. Although this was a large and well conducted study, it did not account for social and socioeconomic status (SES) differences (9). Speculating on the reasons for the higher mortality of short people, Waaler suggested that it was due to socioeconomic factors, poor nutrition and environmental factors. His speculation was confirmed by a 20-year Swedish study by Allebeck and Bergh (10) of 50,000 Swedish men which controlled for different social factors and found that the excessive mortality of short men was almost entirely due to social background factors.

The Whitehall Study by Smith *et al.* (11) found that short people had a higher mortality from all causes. Almost 12,000 male civil servants were tracked for 10 years, and shorter men were found to have a higher mortality from all causes, except cancer. Short stature was related to lower SES. Mortality from CHD increased for short people due to deprivation during infancy and childhood. It should be noted that as nations become more affluent, it is the taller upper classes that first experience increased CHD. Only later does CHD spread to lower [shorter] classes (12). The explanation for this appears to be the increased availability of high-fat and energy-rich foods among the poor as the entire nation becomes more affluent.

Barker *et al.* (13) conducted a 10-year study of mortality rates in England and Wales. Counties with taller populations had lower death rates from chronic bronchitis, rheumatic heart disease, ischemic heart disease and stroke but higher rates from breast, ovary and prostate cancer. The researchers concluded that promoting child growth and greater stature has disadvantages as well as benefits.

Njolstad *et al.* (14) conducted a 14-year cardiovascular risk factor study of 13,266 men and women in Norway. They found that stroke incidence was significantly higher in men than women and was inversely related to height. It was concluded that factors influencing early growth and later lifestyle factors contribute to cardiovascular disease (CVD) in adult age.

Marmot *et al.* (9, 12) studied the relationship between employment grade and CHD in British civil servants. They found men in the lowest grade had a CHD mortality 3 times greater than men in the highest grade. Men in the lower grades were shorter, heavier for their height, had higher blood pressure and plasma glucose, smoked more, and reported less leisure-time physical activity than men in the higher grades. After adjusting for all these factors, there was still a somewhat higher CHD mortality among working class men. The researchers related this higher CHD mortality to early life factors. Their findings are supported by studies in Australia, New Zealand, Finland, Norway, France, Sweden and the US which show that lower social classes have higher rates of heart disease (12).

Palmer *et al.* (15) studied 2,050 women under 65 years of age for 4 years and found an inverse relationship between height and myocardial infarction risk. Another study of 12,695 Swedes by Peck *et al.* (16) found an inverse association between height and CHD incidence and mortality. Excess risk of dying by short people was found to be related to childhood SES and present SES. The study concluded that the risk of early death in adulthood of short people is small, but CHD risk is higher although the degree of this risk is uncertain.

Fogel (17), Steckel and Floud (18) and Floud and Harris (19) have also reviewed health and longevity data related to height. They concluded that taller people are healthier and have a lower mortality based on clinical and epidemiological studies over the last 20 years. Like other researchers they pointed out that height is a major index of social and economic advantage. Their studies support findings that healthful early nutrition and higher SES are critical factors in avoiding premature chronic diseases and death.

Life Expectancy and Longevity of Shorter People

Both intra-population and inter-population longevity findings for shorter people are reported next. The question exists as to whether findings for different populations or ethnic groups can be used to demonstrate a relationship between height and longevity or mortality rates because genetics may be a confounding factor. However, Campbell and Chen (20) reported that hundreds of studies show that populations adopting new dietary practices or migrating to new cultures incur the new culture's disease patterns. This is illustrated by the Pima and Tarahumara Indians who are of the same genetic stock but have a large difference in the incidence of obesity, diabetes and CHD due to diet and lifestyle (21). Ziegler *et al.* (22) reported that numerous studies have established that when Chinese, Japanese or Filipino women migrate to the US, their risk of breast cancer rises over several generations and approaches that of white women. Therefore, the authors of this paper believe that genetic differences due to race generally play a minor role in health and longevity statistics compared to lifestyle, body size and dietary practices.

Longevity of shorter people within the same population. The Japanese have a very long life expectancy, but Okinawans have a longer life expectancy and lower CHD and stroke rates than other Japanese (23). Okinawans are shorter and have a smaller physique compared to other Japanese. Okinawa also has more centenarians than mainland Japan or any other nation in the world; *e.g.*, it has about 40 times more centenarians than that of northeastern prefectures of Japan. Very old people in Okinawa and Japan are quite short as shown in Table 1 (24). Kagawa (24) reported that a warm climate, hard work and genetic factors might explain the reasons for Okinawan longevity as well as dietary practices. However, many populations enjoy a warm climate and work hard but do not compare with the Okinawan longevity. Also, when Okinawans move to the mainland, US or other countries, their lifespans are shortened. Therefore, Okinawan nutrition appears to be related to shorter height and longer life expectancy.

Table 1 Heights and weights of elderly people in Okinawa and mainland Japan

	Okinawans 87–104 yr		All Japan 100–105 yr	
	Males	Females	Males	Females[a]
Height (cm)	145.4	140.0	148.2	137.5
Weight (kg)	42.8	42.2	44.1	36.7

a : The reasons for the lesser height and weight of centenarian mainland Japanese women is unknown. It could be due to their greater age, greater shrinkage, or sampling error.
yr: Year

The 1979 Build Study (25), conducted by the insurance industry and based on about 4.2 million people, found that height had little effect on mortality. However, when tall and short men who were overweight to the same degree were compared, the short men lived somewhat longer. This study also found that short women had a lower overall mortality compared to medium, tall and very tall women. Very short women had about 9% higher mortality than short, medium and tall women, but a 29% lower mortality than very tall women. Some have criticized this study because the population represented a selected group of people who had to be in reasonably good health to be insured. However, this selection process produced a highly homogeneous sample population with similar health and SES.

The Mortality and Morbidity Investigation (26) conducted in the early part of this century reported that tall men had excessive death rates. Another early insurance study (27) found that for ages under 40 years, tall men had the highest mortality in almost every build group and short men generally had the lowest mortality. After 40 years, short men had the highest mortality in underweight and overweight groups, and after 50 in almost all groups (27). Among older men, men of average height usually had the lowest mortality in various build groups. (During the period of this study, the average height of US men was less than 172 cm.)

Polednak's study (28) of former Harvard athletes indicated that shorter athletes lived about 1 to 3 years longer than taller ones. Although the differences in mean age at death from natural causes were not statistically significant, the larger athletes were consistently shorter lived. He also reported that 4 other studies found an 1 to 2 year lower mean age at death from natural causes for athletes compared to non-athletes. As expected, Polednak's report indicated that nonathletes were shorter and lighter than athletes. It should be noted that athletes are a select group in that they require superior cardiovascular, pulmonary, and immune systems to be successfully competitive. Although in theory they should live longer than the general population, study findings are mixed and may reflect the negative impact of greater height or body size.

Miller (29) studied the records of 1679 randomly selected deceased men and women provided by the Coroner's Office in Cleveland, Ohio. Only people who died from natural causes were used for this study. He found an inverse relationship between height and age at death for the entire group as well as for within different ethnic groups and for both sexes. A loss of 0.47 year/cm was found in this study. In unpublished findings, Miller

Table 2 Age/height slopes for various population groups

Slope (year/cm)	Population studied
−0.47	Cleveland men and women: Taller *vs* shorter (29)
−0.45	Rural Chinese males *vs* shorter females (20, 54)
−0.47	California white males *vs* shorter females (30)
−0.63	California white males *vs* shorter Asian males (30)
−0.60	California white males *vs* shorter Hispanic males (30)
−0.47	Veteran's Administration Medical Center: Taller males *vs* shorter males (30)
−0.35	Baseball players: Taller males *vs* shorter males (30)
−0.59	French: Taller males *vs* shorter males (died < 1861) (34)
−0.43	French: Taller women *vs* shorter women (died < 1861) (34)
−0.59	College athletes: Taller *vs* shorter males (28)
−0.41	*Webster's American Biographies*; taller *vs* shorter males (unpublished data from Samaras)
−0.43	*Current Biography Yearbooks*: Taller *vs* shorter males (unpublished data from Samaras)
−0.81	Football Players: Taller *vs* shorter males (32)
−0.52	Average slope for all studies

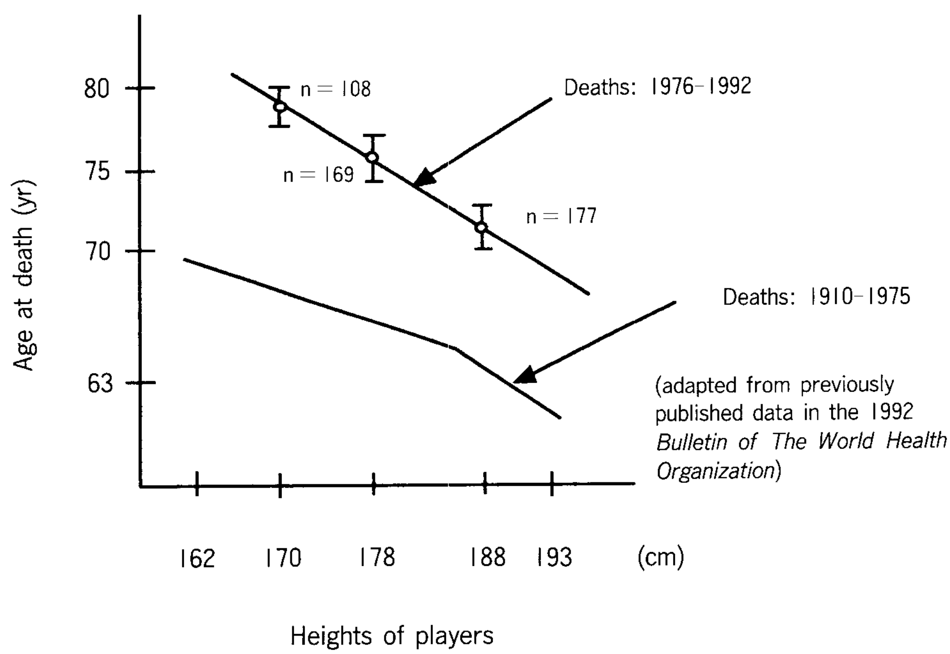

Fig. 1 Reduction in baseball players' average lifespan with increasing height.
Notes: Error bars = $\bar{x}$ +/− $s_{\bar{x}}$, where $\bar{x}$ = mean age, $s_{\bar{x}} = s/n^{1/2}$, $s_{\bar{x}}$ = standard error of the mean, s = standard deviation, and n = sample size. Used with permission of The Washington Academy of Sciences, Washington, DC.

also found professional basketball players had the same decline of 0.47 year/cm with increasing height (personal communication), which is consistent with other study findings shown in Table 2. He also found an inverse relationship between height and longevity for professional baseball players as was found by Samaras and Storms (discussed below). Miller noted that the role of height in relation to longevity was relatively small, and height explained only 10 % of the total variation in age at death.

Samaras and Storms (30) found significant longevity differences between short and tall US veterans and baseball players. Fig. 1 shows the pattern of decreasing life span with height for about 3,600 baseball players who represent a reasonably homogeneous group in lifestyle and diet. Body weight was also inversely related to longevity. A similar pattern was found for 373 deceased veterans at the San Diego Veteran's Administration (VA) Medical Center whose longevities were inversely correlated with both height and weight. A loss in lifespan with increasing height slope of − 0.47 year/cm was found for veterans and − 0.35 year/cm for baseball players. These slopes are close to the slope (− 0.47 year/cm) found in the previously discussed findings (29). A summary of the slopes for 13 different population samples is given in Table 2. The average is − 0.52 year/cm. For veterans, the correlation coefficient between height and average age at death was − 0.23. This is similar to other findings shown in Table 3. Analysis of 200 deceased football players (32) found a decline in lifespan with increasing height similar to baseball players (33) (Fig. 2). Shrinkage with age was not a confounding factor because heights were given for the playing years of the baseball and football players. The veteran's heights were probably somewhat lower than during their youth but this is true for both the shorter and taller veterans. Therefore, their relative height differences were essentially the same.

Samaras and Heigh (34) and Samaras (35) reported findings on over 400 French men and women who died before the year 1861. Fig. 3 shows the results of this study for deceased men. The Δage/Δheight slope for a combined male-female average was a 0.5 year loss in average life span with each centimeter increase in height. Data from the American Cancer Society was also analyzed in this study (34). About 4,600 men and women consisting of 2 groups aged 85-89 years and 90 + years were compared. Short people increased by 5.6 % in the older group (90 + years) while the percentage of tall people decreased by 5.5 %. Shrinkage with age did not affect results because the heights were those obtained upon initiation of the study. Secular growth trend differences in average height for the 2 cohorts (which differed by ~ 7 years) was also not a factor because the 2 populations (85-89 *vs* 90 +) did not undergo a significant secular growth during the period of their youth.

Table 3 Correlation coefficients for height *vs* longevity and coronary heart disease (CHD) mortality

Category	Population sample	Correlation coefficient (r)	Significant (S)/ Nonsignificant (NS)
Height *vs* Longevity			
	US Presidents (4)	− 0.18[a]	NS
	Giants (31)	− 0.21[b]	NS
	Muscle men (7)	− 0.30[b]	NS
	US veterans (30)	− 0.23	S
	Baseball players (33)	− 0.31[b]	S
	Football players (32)	− 0.33[b]	S
CHD/CVD Mortality *vs* Height			
	US Physician's study (44)	+ 0.24[b,c]	NS
	Seven Countries study (63)	+ 0.34[b]	NS
	Chinese study (54)	+ 0.33	S

a : Assassinated presidents not included in calculation of r.
b : Calculated from data provided in source.
c : Specified for relative risk of death rather than for mortality rate.
CVD: Cardiovascular disease.

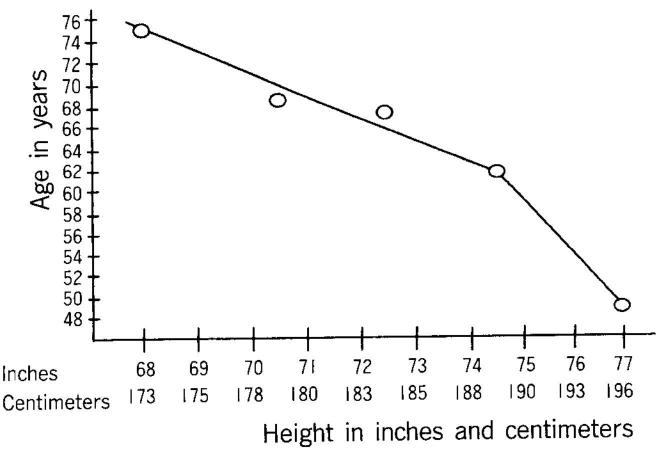

Fig. 2 Reduction in football players' average lifespan with increasing height.
Note: Original height data specified in English units.

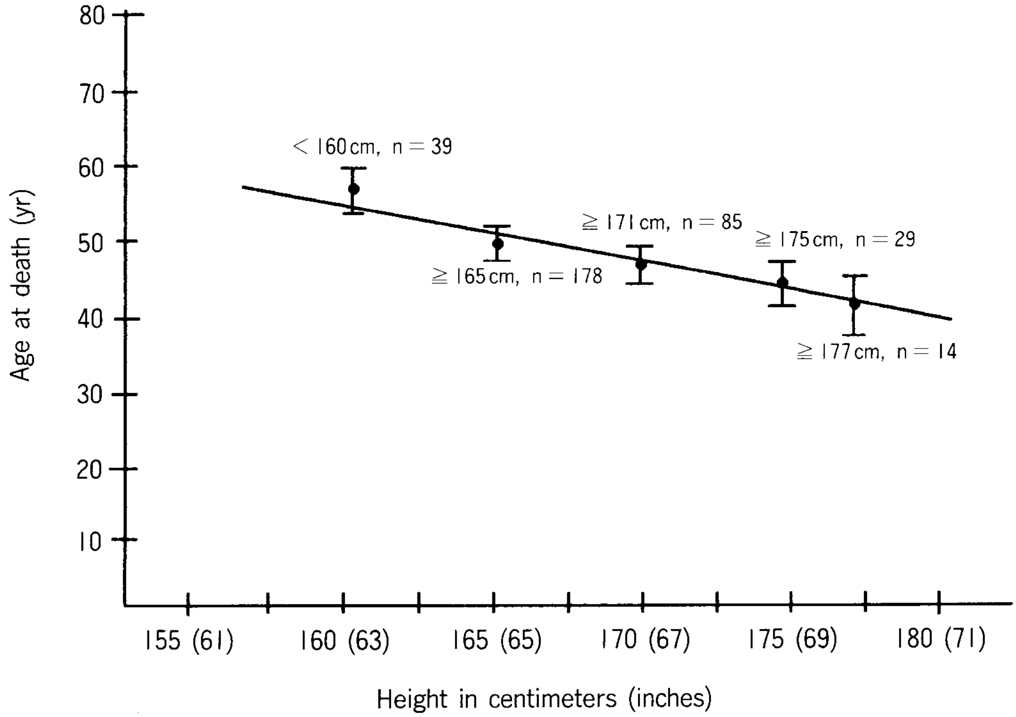

Fig. 3 Reduction in French men's average lifespan with increasing height.
Each bullet represents the average age for a group of men equal to or above a certain height or below a certain height. Error bars = $\bar{x} +/- s_{\bar{x}}$, where $\bar{x}$ = mean age, $s_{\bar{x}} = s/n^{1/2}$, $s_{\bar{x}}$ = standard error of the mean, s = standard deviation, n = sample size. Used with permission of The Washington Academy of Sciences, Washington, DC.

Females in the US average about 13 cm shorter than males and have a life expectancy at birth of about 7 years longer than males (a slope of − 0.54 year/cm), which is close to the slope for short and tall men. Females throughout the world are shorter than men and, with few exceptions, live longer than men. One study found that the difference in longevity diminished or disappeared when men were compared to women of the same height and another found that as the differences in average heights between males and females of different countries decline so does the difference in life expectancy (29, 36). Women also have a higher brain to body weight ratio than men. Some gerontologists believe that a higher ratio promotes greater longevity. While these findings are not conclusive, they indicate a possible explanation for at least some of the difference in male and female longevity (which also exists in much of the animal world). Shorter men also have a higher brain to body weight ratio compared to taller men of the same proportions because the brain increases at a slower rate than body mass (36).

Longevity of shorter ethnic populations. Although China is a developing country, some urban areas have life expectancies of 72.5 years, which is close to that of developed nations. In 1989, Shanghai males had a life expectancy of 73.8 years (37) *vs* 72 years for US males (38) in spite of high pollution, congested living and poorer medical care compared to the West. Most mature Chinese men and women are ~ 9 cm shorter and > 20 kg lighter than Americans (20). A comparison between male Hong Kong Chinese and taller Swedes, the longest living northern Europeans, resulted in a 1.6 year or a 10 % longer life expectancy for the Chinese (39). Like the Japanese, the Hong Kong Chinese have good longevity in spite of widespread smoking, pollution and congestion.

In 1961, Greek life expectancy at the age of 45 years was greater than for any other nation tracked by the World Health Organization (WHO) (40). Greek males in 1961 averaged under 167.6 cm, significantly shorter than northern and central Europeans. Greeks from the island of Crete are even longer lived than those of the mainland and have the longest life expectancy along with Japan (41).

Cretans average about 166 cm (42). According to Nestle (40), subsequent changes in dietary practices and lifestyle have caused a slight drop in the high ranking of Greece. With dietary changes, mainland Greeks and Cretans have grown taller and are experiencing significant increases in CHD and other chronic diseases.

In Western Europe, male life expectancy at birth for 13 shorter countries was found to be 0.6 year longer than for 13 taller nations (7). Analysis of life expectancy at 65 years of age revealed that males in shorter nations lived 0.8 years longer than males in taller nations. This represents a 5.6 % longer life expectancy for shorter, smaller people—many living in countries with lower standards of living, higher relative weights, greater smoking, and poorer medical care. Also, 65-year old males in Japan, Greece, France, Switzerland and Spain live longer than taller 65-year old Swedish, Norwegian, Dutch and Danish males.

California Asians and Hispanics have substantially longer life expectancies than whites and blacks and average 5 to 7 cm shorter than whites and blacks. The life expectancies at birth and for the ages 65–70 are tabulated in Table 4 (43). This study was conducted by the California State Center for Health Statistics for the period 1989–1991. Asians/Pacific Islanders and Hispanics average over 5 years longer life expectancy than taller whites. The largest difference in life expectancy of nearly 20 years was found between Asian/Pacific Islander females and black males. While the Asian diet is an important factor for the longer longevity of Asians, Hispanics follow a much different diet with a fairly high intake of fat. In addition, Hispanics tend to be overweight and of lower income brackets while Chinese and Japanese Americans tend to be economically better off than other ethnic groups, including whites.

Table 4 Life expectancy of California Asians/Pacific Islanders, Hispanics and Whites, 1989–1991

	Asians/Pacific Islanders (yr)[a]	Hispanic (yr)	White (yr)
Life expectancy at birth	81.24	80.22	75.87
Life expectancy at 65–70 yr	20.59	21.41	17.50

a: Life expectancy for this group is lower than previous studies which included only Chinese and Japanese Americans. The authors of this study (43) indicated that the inclusion of East Asians and Pacific Islanders may have caused this reduction. Westernized Pacific Islanders are larger and have higher mortality rates than whites in the same areas (3, 60). yr: Years

Cancer Incidence and Mortality of Shorter People

Cancer within the same population. Hebert *et al.* (44) reported that "Adult height has been found to be positively associated with incidence of cancer in numerous analytic epidemiologic studies, both case-control and cohort" and referenced 21 corroborating studies. The Physicians' Health Study (44), based on 22,000 US male physicians, found that height was positively associated with both total malignant neoplasms and prostate cancer. Hirayama (45) also reported that a series of case-control studies revealed higher breast cancer risk with increased height. He described a study of almost 21,000 women in which women ≧ 160 cm in height and weighing ≧ 65 kg had a cancer incidence risk 17.5 times greater than women < 149 cm and weighing < 59 kg. Eveleth and Tanner (46) reported that in Great Britain the trend for cancer mortality paralleled the increase in the consumption of fat, animal protein and sugar between 1911 and 1971. During this period, height in Great Britain increased as well (19).

Ziegler *et al.* (22) found that height and weight gain were strong predictors of breast cancer risk. A prospective study by Tretli (47) involving 570,000 women in Norway found that in all age groups the tallest women had the highest cancer risk for both morbidity and mortality. Swanson *et al.* (48) found increased breast cancer risk among women who were taller. Freni *et al.* (49) also found a correlation between height and increased cancer risk. Studies by de Waard (50) and Swanson *et al.* (51) reported that tallness (as well as greater frame size) was related to increased breast cancer. While many studies indicate a positive relation between height and breast cancer, some studies have not found a relationship. For example, Zhang *et al.* (52) did not find height related to increased risk of breast cancer; however, in a subsequent study (53), they found that women with the greatest bone mass were at 3.5 times higher risk for postmenopausal breast cancer than those with the lowest bone mass.

An on-going study in China by Chen *et al.* (54) found that death from all cancers was positively correlated ($r = 0.44$) with height with a significance of $P < 0.001$. In this study of 65 counties, cancer deaths were also found to increase with body weight ($r = 0.47$, $P < 0.001$). This study was conducted under the auspices of Chinese Academy of Preventive Medicine with the support of American and United Kingdom researchers and institutions. This study has several advantages over most studies conducted in the West; *e.g.*, a population that has lived in the same area most of their lives, common ethnic background (mostly Han), and stable long-term dietary patterns.

Giovannucci *et al.* (55) found that height and body mass index (BMI) were associated with higher risk for colon cancer in men. The study was based on 47,723 male health professionals 40 to 75 years of age. Another study by Severson *et al.* (56) found a significant positive association for risk of prostate cancer with muscle mass and reported that lean body tissue mass may play a bigger role in increased risk of prostate cancer than body fat. They also found that prostate cancer increased with leg length, BMI and weight.

Albanes *et al.* (57) found that cancer risk was significantly lower in short people. The study was based on 12,554 Americans 25-74 years old with a 10-year follow-up. Data were obtained from the US National Health and Nutrition Examination Survey. The researchers suggested that excess nutrition early in life has a role in human carcinogenesis.

Cancer and different ethnic groups. Albanes and Taylor (58) conducted an international study of 24 populations. For men, they found significant positive correlations between height and cancers of the central nervous system, prostate, bladder, pancreas, lung and colon. In women positive correlations were found between height and cancers of the rectum, pancreas, ovary, central nervous system, uterine corpus, breast and bladder.

US Asians and Hispanics have a lower cancer mortality compared to taller whites and blacks. According to the National Center for Health Statistics (NCHS) (59), the age-adjusted cancer mortality rates per 100,000 male resident population were as shown in Table 5 for the period 1993-1995.

Table 5 Age-adjusted male cancer mortality rates in the US[a] 1993-1995

Ethnic group	Mortality rate
Native American and Native Alaskan males	92.7
Hispanic males	97.8
Asian males	99.7
White males	154.2
Black males	232.7

a: Asians and Hispanics are generally smaller than whites and Blacks. Native Americans vary from short to tall depending on their tribe and socioeconomic status; The Navajos, the largest US tribal population, are generally shorter than whites. Native Alaskans are relatively short.

Heart Disease and Mortality of Shorter People

Although heart disease has afflicted humankind for thousands of years, only recently has it reached epidemic proportions according to the WHO (2) and Burkitt (60). Before 1900, people were several centimeters shorter than they are now. Even today many populations of shorter people in developing countries have very little CVD and hypertension.

Heart disease within the same populations. As mentioned before, a number of studies have found that short people have higher death rates from heart disease and strokes. However, the Framingham study (61) found no increased risk of death from all-causes or CVD mortality by height in either sex. Hebert *et al.* (62) found a higher incidence of myocardial infarction (MI) for short people but no significant difference in death rates from stroke and CHD were observed. Subsequent analysis of Hebert's mortality data by Samaras and Heigh (34) revealed an increase in relative risk from 0.83 for the shortest to 1.21 for the tallest physicians. Hebert *et al.* also found that systolic blood pressure increased slightly with increasing height. Table 3 compares the correlation coefficients from the Physician's Study (62), Seven Countries Study (42, 63) and the Chinese study (54).

Higher death *et al.* rates from heart disease were also found for taller men in a study of 50,000 males conducted in Sweden (10). Earlier in this century, Davenport and Love (64) evaluated US data on over 2 million WWI recruits and found that taller than average men were especially prone to cardiac disorders. Benfante (65) provided CHD and stroke mortality rates for Hawaiian and California men of Japanese extraction. The taller and heavier California Japanese had higher CHD and stroke rates. California Japanese weighed 3 kg more and were 1 cm taller than Hawaiian Japanese. For men 60-64 years of age, the CHD death rate was 3.9/1,000 for the shorter men *vs* 4.9/1,000 for the taller. The taller and heavier men had over twice the death rate from strokes as the shorter men.

Heart disease for different ethnic groups. Burkitt (60) studied autopsy data from over 1,000 hospitals in developing nations and found these people were generally free of diseases common in affluent countries until they began following a Western type diet and lifestyle. Although the overall life expectancy of these countries is low, they have many elderly people. For example, over 60 % of the world's elderly people (≧ 60 years) live in developing countries (66).

Tao *et al.* (67) reported that China's death rate from CHD is 1/10 that of North America and Australia. Guangzhou [Canton] was found to have the lowest CHD risk in the world. However, during the last 3 or 4 decades CHD has increased in China and is associated with dietary changes and increased serum cholesterol levels, blood pressure and smoking. Although middle-aged men were still relatively short (~ 164 cm) in 1990, the Chinese have been increasing in height at about 2.54 cm/decade during the last 40 years (54). Chen *et al.* (54) found that taller men and women had higher death rates from MI and CHD with a correlation coefficient of r = 0.33 for height with a $P < 0.001$. Table 3 compares this correlation coefficient with coefficients from the Seven Countries Study and US Physician's study.

Nestle (40) pointed out that since the 1960's, certain Mediterranean countries have rates of chronic diseases that are among the lowest in the world and life expectancies that are among the highest. Renaud *et al.* (41) also reported that CHD deaths in southern Europe were 1/2 to 1/3 the rate for northern Europe and the US. Additionally shorter southern Italians have lower CHD death rates than taller northern Italians (68, 69).

Like cancer, heart disease mortality is lower among shorter Asian and Hispanic Americans. A NCHS report (59) indicates that age-adjusted mortality per 100,000 resident population for males due to heart disease is 107 for Asians, 124 for Hispanics, 144 for Native Americans, 184 for whites, and 259 for Blacks. Age-adjusted cerebrovascular mortality rates per 100,000 for various ethnic males are: 22 for Native Americans, 23 for Hispanics, 27 for whites, 30 for Asians, and 52 for Blacks.

Rural South African Blacks, Australian Aborigines, Eskimos, Asians and Taramuhara Indians are relatively short and have traditionally had very low blood pressure and CHD disease (70-72). It is interesting to note that Australian Aborigines following a traditional lifestyle had a low BMI range of 13.4 to 19.3 m/kg^2 but showed no biochemical evidence of malnutrition and had low CHD (71). The Sami (Lapps) are short people and Luoma *et al.* (73) reported that they have exceptionally low CHD mortality. The Seven Countries Study found that the Japanese had a lower death rate from CHD compared to most European countries. However, shorter men from Ushibuka had much lower death rates from CHD and stroke than taller men from Tanushimaru (42). As these populations become westernized, disease patterns change towards those of developed countries (60).

Body Size and Longevity

Body size in this paper is used to refer to a combined height and weight. However, body weight independent of height in itself is also a measure of body size. The Quetelet body mass index (BMI = wt/ht^2) is commonly used as a measure of relative weight. BMI is specified as kg/m^2 and epidemiologists generally use this index as a measure of fatness. However, a WHO Expert Committee stated that "....BMI does not measure fat mass or fat percentage...." (74). Therefore, BMI is more likely a measure of body mass which may or may not involve obesity.

The optimum BMI for lowest mortality is controversial but the consensus appears to be that lower is better. However, some researchers, like Fried *et al.* (75) and Andres (76) have found being slightly overweight is more healthful. In contrast, Stevens *et al.* (77) completed one of the largest obesity studies to date involving 62,116 men and 262,019 women (non-smokers) over a 12-year period. They found that a BMI of 19 to 21.9 had minimal risk in most age categories although relative weight became less important after 75 years of age. Shaper *et al.* (78) found a BMI of 20-23.9 had the lowest mortality risk and < 20 was best for minimum CVD, heart attack and diabetes risk. However, all-cause mortality increased for men with BMI < 20 and ≥ 30. Another study (79) involving 115,000 nurses, found a BMI < 19 had the lowest mortality. A Harvard study by Lee *et al.* (80) based on 20,000 middle-aged Harvard graduates found the healthiest men weighed 20 % below average for men of the same age and height. A Dutch study (81) of 78,000 males tracked the mortality of 18-year olds for 32 years based on their BMIs at the inception of the study. The researchers found that a BMI range of 19 to 19.99 had the lowest mortality.

Launer and Harris (82) studied people from 19 geographically and ethnically varied samples of elderly people (60-89 years of age). They reported large differences in the prevalence of overweight and underweight. However, in virtually all studies mean height and BMI decreased with age and the proportion of people with a BMI < 20 increased with age (82). In contrast, in a relatively small

Finnish study, Mattila (84) found that mortality declined with increasing BMI. The WHO (2) reported that thinness was prevalent in a majority of studies of elderly people, and the Framingham Study found mortality increased with increasing BMI for people > 65 years of age (83). Matsuzawa *et al.* (85) found that the minimum mortality for the Japanese was at a BMI of about 22, and the American Cancer Society reported that thin people had better survival over time (86).

A 26-year study by Lindsted *et al.* (87) found that the BMIs of 8828 vegetarian Seventh Day Adventist (SDA) males were inversely related to average age at death. (Fig. 4.) A linear decline in age at death was seen over five BMI groupings ranging from ≤ 22.3 to > 27.5. (US average is ~ 26.) The men, in the lightest grouping lived 4.7 years longer than those in the heaviest group. Their average age at the start of the study was about 52 years. Based on Fig. 4, the loss of life for these men with each 1 point increase in BMI was 0.8 year. This is somewhat lower than for the younger athletes in Samaras' and Storms' (30) study. A recent analysis of their earlier baseball player data found an average loss of 1.07 years for each height group for each point increase in BMI. The SDA study was a large and long-term study based on a relatively homogeneous population sample. Educational level, diet and marriage status were similar for the majority of the SDA men. Most did not smoke. Another factor increasing the validity of the findings is that very thin men were thin due to choice of diet and lifestyle and not due to smoking, poor diet or illness.

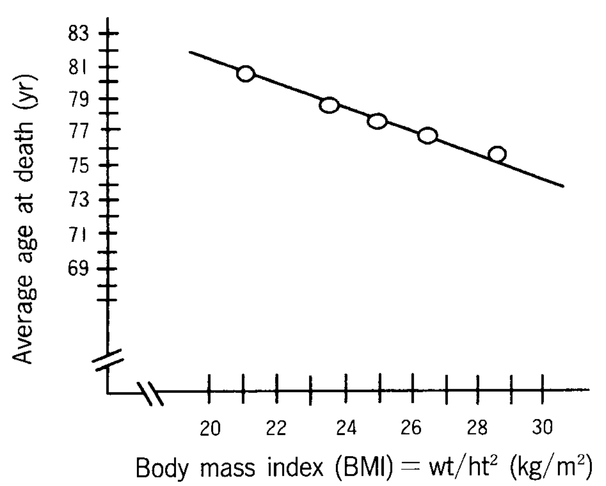

Fig. 4 Reduction in average lifespan of Seventh Day Adventist males with increasing BMI.
Plot point of BMI = 21 is estimated based on BMI of ≤ 22.3 given in source. Plot point of BMI = 28.5 is estimated based on BMI of > 27.5 given in source.

Micozzi (3) reported that Mexican-American and Japanese-American migrant population samples have seen a rising trend in rates for cancer, CHD and other chronic diseases over succeeding generations. These changing rates are partially attributed to greater growth rates and increased childhood and adult stature and weight. He also reported that stature is a measure of nutritional exposure during childhood and adolescence and appears to be important in promoting the long-term risk of chronic diseases.

The US National Institute for Occupational Safety and Health (88) conducted a study of 6,848 National Football League players. It found that offensive and defensive linemen had a 50 % higher risk of dying from heart disease than the general population and 3.7 times the risk of dying from heart disease than other smaller football players. Leaf (89) also reported that the mean age at death for football players was 57 years. Samaras recently evaluated weight and longevity data (32) on professional football players and found that longevity declined with increasing weight from 77 kg to 114 kg.

The Honolulu Heart Study also found that the men with the lowest BMI at 25 years of age had the lowest mortality in middle age providing they did not lose weight after 25 years of age (86). The median BMI at 25 years of age was 19.8 kg/m^2. (A BMI of 20 kg/m^2 is close to that of a marathon runner.)

Elrick and a team of scientists (21) visited 8 areas in the world noted for their vigorous and long living people. This team consisted of physicians, exercise physiologists and nutritionists. Based on extensive observations and evaluation, a BMI of 19 to 22 (BMI increased with height) was found ideal for good health and long life. Other researchers such as Leaf, Smith, Davies and Georgakas studied a variety of long living people in several parts of the world and found that thinness was their most common characteristic (7, 21, 90).

Caloric Restriction, Body Size, Health and Longevity

Nutrition, height and body size are related. Generally children who eat more protein and calories are taller and heavier as adults and may or may not have excess fat. Because malnutrition and short life expectancy were common during many years of the Industrial Revolution, dietary recommendations were developed to avoid the negative aspects of inadequate intakes of protein, fat, minerals, vitamins and joules or calories. In addition, growth velocity tables for children were developed to measure their physical development. Failure to meet standard growth velocity is viewed as a health problem related to dietary or other deficiencies in the child's environment. Unfortunately, most health practitioners are convinced that failure to meet one's maximum potential for height reflects a poor diet. As a result, a worldwide trend towards greater height has also led to greater obesity with the US leading the world. However, based on many studies, a balanced but low fat and low calorie diet may be more healthful in the long run for the child. But since a significantly reduced fat, calorie and protein diet will result in shorter stature, most health practitioners oppose reduced food intake. The following material is presented to show that a well-balanced diet low in calories or fat is beneficial to the health of children or adults even though some reduction in height may occur when applied during the growth period.

One of the most effective means for producing healthy, long lived animals is through caloric restriction (CR) starting after weaning. Longevity benefits are also obtained if CR is started in adulthood but the benefits are less. McCay *et al.* (91) first demonstrated the effectiveness of this technique about 60 years ago. The protocol usually involves a 30 % to 60 % reduction in calories compared to ad libitum feeding. The animals grow more slowly and do not reach the body sizes of animals allowed to eat all they want. The resulting benefits are healthier animals that may reach twice the maximum age of animals allowed to eat all they want. The increase in longevity is proportional to the amount of restriction applied; *i.e.*, a 40 % reduction in calories can equal about a 40 % increase in longevity. A conference on caloric restriction reviewed the findings to date and concluded that preliminary results of CR studies with monkeys and humans are "strikingly similar to the data found with rodents, strongly implying that these variables may operate across species and sexes and thus be reasonable markers for rates of aging" (92).

McCay's findings have been successfully duplicated numerous times by other researchers. Masoro (93) has observed that restriction of energy intake rather than a specific nutrient underlies the anti-aging action of caloric/dietary restriction. Caloric or dietary restriction has been successfully applied to worms, mice, rats, dogs, fish, spiders and protozoa. Based on this and other evidence, Comfort (94) stated: "...optimum level feeding for rapid growth produces a much shorter life span than a diet that checks growth without causing specific vitamin deficiencies." Another study by Rollo *et al.* (95) involving giant transgenic mice found that they lived half as long a normal size mice. Additionally, transgenic mice on a high-protein diet (which promotes greater body size) experienced reduced longevity. For over 10 years, CR has been applied to primates with excellent results. Based on their evaluation of extensive CR data, Hass and 19 other researchers (92) in this field believe it is time to apply the technique to humans.

CR can reduce body size of children and adults. Reduction in height, however, occurs only when CR is started during the growth period of a child and depends on the extent of this restriction (6, 91, 92). When CR is started as an adult only body weight is reduced (96). Evidence supporting the healthful benefits of CR with an otherwise nutritious diet for children and adults follows:

Okinawa. Okinawan children receive almost 40 % fewer calories than those on the mainland of Japan. As adults they consume 20 % fewer calories than mainland adults. Okinawans experience about 40 % lower death rates from CVD and cancer and have many more centenarians than the mainland (24). They also work into their 80's and 90's and are very fit. Kagawa also concluded that their longer life may be due to their lower energy intake (24).

WW II dietary restrictions. Walker *et al.* (70) reported that during WW II populations with the most severe dietary restrictions experienced reduced incidence of diabetes and CHD. All-cause lower death rates were also observed in Norway for various age groups (97), and Castelli observed the absence of atherosclerosed arteries during autopsies in Belgium (98). In addition, deprived of meat and butterfat, Finland and Sweden saw a sharp drop in atherosclerosis. Survivors of holocaust prisons were also free of atherosclerosis.

Madrid study. Vallejo (99) reported that 180 people over 65 years of age in a Spanish nursing home were subjected to a restricted feeding experiment. Ninety were put on a reduced energy intake every other day while the other 90 ate regular meals. Those on regular meals received 9.64 mega-joule (MJ) per day and those on restricted meals received 3.72 MJ one day and 9.64 MJ the other day. The experiment was conducted for 3 years with the restricted group experiencing half the death rates as the fully fed group.

Dutch study. A Dutch study was conducted to test the effects of CR on 24 healthy humans of normal weight. Velthuis-te Wierik *et al.* (100) found that a 20 % energy restriction for 10 weeks improved blood pressure and lipid profile without adverse effects on physical and mental performance and feelings of hunger, satiety and mood. In addition, the subjects had a significant weight loss, a decrease in fat-free mass, and a fall in resting metabolic rate (96).

Australian aborigines study. O'Dea (71) found that Aborigines following western dietary and lifestyle practices had very high incidence of obesity, adult diabetes, hypertension, CHD and insulin resistance. A study was conducted to determine the effects of a reversion to their hunter-gather lifestyle and diet. Within 7 weeks, it was found that the traditional diet resulted in a very low energy intake of 5.03 MJ (1,200 kcal). The results were a considerable improvement in many health parameters. The Aborigines lost weight, fasting glucose concentration fell sharply, insulin response improved, triglycerides became normal, and a number of other CVD risk factors were reduced. In addition, in spite of the low energy intake, a high level of physical activity was necessary to obtain enough food to satisfy their basic needs.

Masai study. Murray *et al.* (101) conducted a 12-year study on the health and survival of 403 undernourished and 386 normally-nourished Masai 18-35 years of age. The researchers found that chronic undernutrition had no adverse effect on mortality or morbidity and infections, especially malaria, were much lower in the undernourished. Incapacitation due to illness was also much lower in the undernourished.

Biosphere 2. A low-energy nutrient-dense diet was followed for 2 years by the 8 people isolated in the sealed Biosphere 2 (102). Many benefits were seen in the Biosphere team, including significant reductions in blood cholesterol, fasting blood sugar, white blood cells and body weight. Energy intake was between 7.5 MJ and 9.2 MJ/day or about an average of about 2.1 fewer MJ than had been originally planned. The diet was primarily vegetarian with small amounts of meat.

Czechs and Guatamalans. Hejda (103) reported that a study of very old Czechs found that all of them came from large, poor families and had a very modest or even insufficient diet during their childhood. Dubos (104) studied Guatamalan natives and found them to be calorie and protein deficient, short and frail looking (energy intake was only 6.3 MJ/day). Yet, they were capable of much harder physical work than robust Europeans and North Americans and often lived to old age.

Albanian study. Although Albania is the poorest country in Europe, life expectancy at age 15 is the same as that in the UK and Portugal. Gjonca and Bobak (105) attribute this good health to "....low consumption of total energy, meat, and milk products but a high consumption of fruit, vegetables, and carbohydrates." In addition, people from the southwestern part of Albania have about 1/2 the mortality as those from the northeast. Yet, socioeconomic conditions are equally poor for the whole country. The researchers attributed the higher mortality in the north to consumption of more food and fats of animal origin whereas the southerner's diet includes more olive oil, fresh fruit and vegetables.

People of the Vilcabamba, Hunzaland, and Abkhasia. Several researchers, including Leaf (89), Georgakas (90) and Elrick *et al.* (21) found many elderly people in these three remote areas to be vigorous, active and healthy. They lived on diets ranging from 5 MJ to 8 MJ/day——energy intakes below those of developed countries in spite of their physically active lifestyle and harsh environments.

Other findings. Walker *et al.* (5) found African children on low food intake were shorter as adults, free of CHD, and had very low death rates from diet-related cancers. A study by Frankel *et al.* (106) evaluated the cancer mortality of 3,834 English males and females over a 58-year period age. For both men and women, those who consumed a lower energy intake during childhood had a lower cancer mortality. The researchers found an increased energy intake of 1 MJ/day (239 kcal/day) in childhood was correlated with a 20 % increased risk in adult cancer mortality.

The British nobility, not known for its sparse diet, compares poorly with the energy-restricted long-living Okinawans (23, 24). In over 1,000 years, British nobility has produced only one centenarian (89). While this may be due to a poor diet, short and small centenarians, such as the Hungarians, have been reported to have had inadequate diets as well (103, 107).

Under the sponsorship of the Gerontological Center of the Semmelweis Medical University and the Hungarian Central Statistical Office, Eiben and Bodzar (108) studied the physical characteristics of 109 centenarians and found them to be very short. Men averaged 153.6 cm and 55.6 kg and women 142.2 cm and 46.3 kg. This is quite low compared to the average Hungarian adult stature between WW I and WW II, which was 167.0 cm for males and 156.1 cm for females. A comparison between the number of people $\geq$ 100 years of age between 1870–1930 and 1940–1987 revealed that there were 60 % more centenarians during the earlier period. While shrinkage and poor posture played a role in the Hungarian's short height, it is difficult to estimate their heights during youth. However, studies indicate that shrinkage would range between 5 and 7 cm.

Of 13 European countries (108), the countries with the highest number of people $\geq$ 100 years old per million population included 1 relatively tall country, Ireland (70/million), and 3 shorter nations: Bulgaria (199/million), Spain (87/million), and Portugal (66/million). Another shorter nation, France (69), had the greatest number of people $\geq$ 99 years at 148 per million. These findings were based on population censuses conducted during the early 1980's.

It is important to realize that low energy regimes, such as the traditional Mediterranean diet, may still not be optimal. For example, the Cretans consumed 40 % of their calories from olive oil and other fats about 40 years ago. When they were farmers they burned off this energy, but with a more sedentary life, a significant reduction in fat/oil intake would be sensible. Other low calorie diets may be highly deficient in important macro- and micro-nutritients and are therefore not health promoting.

Support for Smaller Body Size from Animal and Plant Data

Data from animal research showing that smaller body size is more healthful and has greater longevity are highly convincing to those scientists familiar with CR and body size studies. For example, Andrzej Bartke, Professor of Physiology at Southern Illinois University, has stated that body size is a major determinant of life span within a species based on findings from animal research (personal correspondence). Austad (109) also reported that within a species, larger individuals have shorter longevities. Rollo *et al.* (95) also reported that larger individuals within a species have rapid growth and accelerated aging. Comfort (94) found that within a mammalian species, the smaller-bodied live longer than the bigger. (In contrast, larger animals of different species generally live longer.)

Although CR may be the dominant mechanism for increasing longevity, small size without CR can also produce greater longevity. Ross *et al.* (110) found that body weight was correlated with longevity independent of dietary practices. Also Austad (109) reported that smaller drosophila, flour beetles, dogs and house mice lived longer. Smaller breeds of dogs, horses and elephants (111) live longer but these animals are not smaller because of dietary or CR. Brown-Borg *et al.* (112) found genetically small dwarf mice without CR lived much longer than normal mice. Dwarf mice were normal size at birth but grew to only 1/3 the size of normal size mice. Dwarf and normal size mice were fed lab food and tap water without restriction and lived in the same environment.

A comparative study of 23,535 pet dogs was conducted by Patronek *et al.* (113). They found that body size was inversely related to lifespan. The researchers also noted that the large variation in body size among dogs was associated with considerable variation in longevity, despite similarities in physiology, diet and environment. The study also found that the onset of most neoplastic and degenerative disease starts at an earlier age in larger breed dogs than smaller breeds.

Plants also provide evidence of the greater longevity of smaller sizes. The bristlecone pine is only about 9 m [30'] in height and much shorter than most trees. It is the world's longest living tree (4,600 years) and exceeds the life expectancy of the much taller Sequoia by over a 1,000 years (114). The creosote is a desert bush which is a rather sparse and relatively small plant (~ 2.5 m) but its life span is over 11,000 years. The miniature Bonsai live as long or longer than normal size trees and shrubs (114). In addition, dwarf eastern white cedars growing on cliffs bordering Canada and the US are long lived (115). These trees are one of the slowest growing in the world due to a harsh environment and lack of nutrients. Normal size cedars growing on flat ground average about 15 m [50']. However, most of the stunted cedars are less than 3 m [10'] and look like seedlings at 20 years of age. Some of these trees are over 1,600 years old compared to normal size white cedars which average about 90 years.

Theoretical considerations. There are several important theoretical reasons for smaller bodies living longer. These include fewer body cells, less work for the heart, decreased intake of toxins, lower amounts of free radicals, lower body temperature and oxygen consumption and lower entropy (disorder).

A 154 cm person weighing 50 kg has about 40 trillion fewer cells than a 183 cm person weighing 86.4 kg (35). These additional cells are equally subject to mutations that can lead to cancer from exposure of the cell's DNA to high-energy photons, cosmic rays, ultraviolet radiation and toxins.

The average human body contains about 100,000 km of blood vessels. A small body will have a smaller network than a bigger person. This network of blood vessels should increase in proportion to body mass and linear dimensions. The number of capillaries increase in proportion to $mass^{3/4}$ (116) which is equivalent to $height^{2.2}$. Thus, the heart has to work harder to pump more blood through a longer and more complex network of blood vessels (30). This may be the reason for the short lifespan of giants and for the higher death rate from CHD of larger football players (88). It should be noted that short people who consume amounts of meat and other fat-rich foods in similar quantities to Americans may be at higher risk for CVD because their smaller blood vessels are more likely to get clogged (35). Shorter people in the West tend to be more overweight than taller ones because food portions are not adjusted for size. Thus short people often eat more in proportion to their basic size than tall people. Only a 2 % excess energy intake over 10 years will result in a 20 kg weight gain. A life-long slightly lower energy intake in proportion to height may also explain why many very tall people have lean builds.

A larger body subjected to the same lifestyle and occupation as a smaller one will require more food and water in proportion to its mass (7). Thus, the intake of pesticides, mercury, PCBs and toxins will be greater. Since cancer usually starts in one cell, a larger body will not provide greater protection unless the immune or repair systems are better. Data from animal studies indicate that energy-restricted smaller animals have lower metabolisms and better immune systems (92, 95, 117).

Lower body temperature and oxygen consumption have been found among rodents and primates subjected to CR (92). Both these changes can result in fewer free radicals and fewer cell divisions and these changes are believed to promote greater longevity.

The brain increases at significantly slower rate in proportion to increased body mass (118). Thus, taller people of the same proportions as shorter ones will generally have a lower brain to body weight ratio. Some researchers have found a correlation between this ratio and longevity. This also appears to hold true for women in comparison to men.

Hayflick (111) found that the human species had a maximum number of about 50 cell doublings over a lifetime. Since a larger body requires more cell doublings during its growth phase, the number of cell doublings left over one's lifespan will be less. This could shorten the longevity potential of large people, depending on other risk factors.

Leaf (119) and Roth (107) described the Second Law of Thermodynamics (also known as the Law of Entropy) as a fundamental basis for the aging process. Leaf observed that matter in our universe moves towards increasing randomness and disorder. The survival of living beings depends on highly organized arrangements of matter and require ordered energy from the outside world to repair disordered or malfunctioning body elements. Thus, a constant intake of energy is required to maintain our bodies in working order. Unfortunately, this reordering process is not perfect and some damaged or defective cells or DNA remain and accumulate over time. Samaras (120) proposed that this process would be accelerated in larger bodies because increased mass and energy intake promote the opportunity for greater disorder. He postulated that the optimum human configuration would require a minimum energy — mass combination. Thus, he predicted that a smaller body, everything else being equal, would age slower.

Validity of Findings and Other Considerations

The findings suggesting that shorter or smaller humans tend to be healthier and longer living are highly consistent in spite of widely divergent population samples and show that average lifespan declines by a standard amount with increasing height (29, 30, 34, 35). For example, when study findings with widely divergent populations are compared, the age/ht slope varies between − 0.35 year/cm and − 0.81 year/cm, providing an average value of − 0.52 year/cm with a standard deviation of 0.12. The findings of this paper appear to have general application to all humans because:

- A wide range of different groups show a negative correlation between height and longevity.
- Considerable data show lower cancer rates among shorter people.
- The lowest rates of CHD and diabetes are found among some of the shortest and smallest people on the planet.
- Animal studies and experiments support the findings of these studies. The common genetic background, diet, environment and lifestyle of test animals eliminate most confounding elements found in human studies.
- Several theoretical considerations provide plausible explanations for these findings.

Findings from the Lindsted and Samaras/Storms studies show a similar loss of life expectancy with increasing BMI. Since many studies have found low BMI's promote greater longevity (81, 86, 87), it appears that tall people of the same body build as short people will have a somewhat lower life expectancy due to their larger BMI if other factors, such as SES, are similar. However, tall people who have low BMI's can live longer than short people with high BMI's.

Most centenarians appear to be relatively short and small, possibly due to a cohort effect (121). Of course, some shrinkage accounts for this, but a 183 cm, 86 kg person is still not small in old age at 178 cm and 77 kg. If the studies indicating taller people are healthier were valid, there should be a disproportionate number of tall centenarians. This does not appear to be the case. As mentioned, the normally tall British nobility had only 1 centenarian over a 1,000 year period. Early in American history, US Presidents, Washington (188 cm), Jefferson (189 cm), and Jackson (185 cm) were tall. Yet, their average lifespan was significantly less than shorter Presidents (4). An evaluation of 3,600 deceased baseball players also found a much higher percentage of shorter men in their 90's compared to taller men (33).

Animal experiments and studies have also consistently shown that smaller animals live longer. Conflicting findings have been rare according to Weindruch and Sohal (117), and the Little Rock Conference on CR reported that reduced energy intake, lower body weight, and longevity were strongly correlated in animal studies (92).

Causes of death. Life expectancy studies included deaths from all causes and the impact of accidents, suicide, or murder on the findings is not known. However, Allebeck and Berg (10) found short people had a 210 % higher death rate from suicides, injuries and undetermined causes. Government findings (59) from the US have also shown that Hispanics under 44 years of age have a higher death rate from violence compared to whites (59). Thus, it is likely that shorter people would have increased life expectancies if these causes were excluded from the data. In addition, the findings are consistent with other studies, such as longevity studies conducted on athletes (28), the general population in Cleveland (29), and veterans (30), which were based on deaths due to natural causes. Baseball and football player data (Figs. 1 and 2) excluded deaths from accidents or violence when sources provided this information. Causes of death for French men and women (34) were not given and probably included deaths from accidents or other non-natural causes. Since the age/height slope and general decline of average lifespan with height was similar to other findings using only natural causes, it appears that non-natural deaths did not seriously affect the validity of the findings. The SDA study (87) excluded deaths from poisoning, accidents and congenital malformations.

Evolutionary considerations. Gibbons (122) reported new paleontological findings which challenge the traditional belief that modern humans are superior because evolution has made us taller and bigger brained than our predecessors. Ruff *et al.* (123) studied ancient human remains and found that body and brain weights have been declining for the past 50,000 years. The average Pleistocene specimen was 7.4 kg larger than today's humans. This trend was reversed when we developed the means to produce large quantities of energy-dense food following the Industrial Revolution.

Certainly both large and small species flourish in our world. However, Gould (124) has noted that small forms predominate as they have for billions of years, and biologists no longer view large species as inherently superior. Paleontologist Raup (125) noted that a study of large and small species found that species ≥ 45.5 kg had a seven times higher extinction rate than species < 45.5 kg. Researchers have also found that as primates get bigger and eat more meat, their population density declines (126). It appears that nature adjusts the number of animals downward as individuals get larger to prevent them from destroying their habitat.

Confounding factors. It is possible in animal studies to control a variety of factors which are difficult if not impossible to control in human studies. Socioeconomic status during youth and adulthood, heredity, BMI, environment, lifestyle, diet and smoking are major confounders (4, 12). Other confounders are availability and quality of medical care, prenatal and lifetime nutrition, alcoholic and drug consumption during or preceding pregnancy, and childhood diseases——all of these can affect study results and conclusions (Table 6). The extent of their impact, however, is unknown. Several confounders are discussed next in relation to the findings in this paper and for consideration in future studies.

The difference in life expectancy between tall/big and short/small people should converge with age as occurs between women and men and whites and blacks. The reasons for this trend is that tall or big people that survive to a greater age are a select group and have already

Table 6 Confounding factors that may affect results of height *vs* longevity/mortality studies[a]

- Socioeconomic status, lifestyle and educational level affect mortality rates/longevity
- Use of Quetelet Index *vs* Ponderal Index/Khosla-Lowe Indexes can affect results
- Congenital heart disease can cause stunting and premature death
- Numerous childhood diseases, such as rheumatic fever can cause stunting and premature death in adulthood
- Energy intake and diet quality during growth and adulthood affects longevity
- Causes of death should be due to natural causes or illnesses; short stature can affect behavior due to psychosocial factors which lead to an excess of suicides, substance abuse and violent deaths. AIDs is often higher in lower social classes.
- Secular growth and shrinkage with age can affect the longevity *vs* height relation
- Heavier weight for height of shorter people can provide misleading results
- Tall, thin people can live longer than short, heavy people
- Greater smoking among shorter people can reduce longevity significantly
- Mother's diet and health during pregnancy can affect child's growth and future health
- Mother's lifetime diet may affect child's growth and health
- Pre and post natal medical and family care can affect growth and future health
- Malnutrition or poor nutrition can affect growth and future health
- Smaller diameter blood vessels in shorter people are more likely to develop atherosclerosis on western diet and cause premature coronary heart disease problems
- Premature birth or low birth weight appears to have negative health impact in adulthood
- Heredity can affect longevity significantly, independent of height
- Cohort differences may affect findings when populations of different birth years are compared
- Self-reported heights are usually 2.54 cm higher than actual heights and may require data adjustment for some studies
- Psychosocial factors can affect height, health and longevity

a: Most of these confounders, if not corrected for, will provide mortality or longevity results which will be biased in favor of taller people.

avoided premature death.

Use of the Quetelet BMI is a problem in epidemiological studies evaluating height against health and longevity. The ideal BMI (ht/wt^2) is a good measure of what is the best weight for height to achieve minimum mortality. However, when used to compare the mortality of short *vs* tall people, it can provide misleading results because the physique of short people will differ from that of tall people. For example, short people tend to be stocky while tall people tend to be lean even though they have the same BMI.

Galileo discovered many years ago that body weight increases as the cube of the increase in linear dimensions. Biologists have confirmed this pattern in the animal kingdom and comparison of humans over different periods have shown that weight increases as the cube of the increase in body height. For example, Gersh and Litt (127) reported that each taller generation has increased in weight by about 4.55 kg, which exceeds the cube of height increase. Damon (128) found in a study of four generations of Harvard men that body weight increased as the cube of the increase in height. Samaras in unpublished findings found secular weight-height changes in the US, Hong Kong, Norway, Zagreb and Japan generally correspond to the Ponderal Index ($wt/ht^{-1/3}$). Another method (129) for determining the proper weight of a taller person compared to a shorter one is the following: $wt_t = wt_s (ht_t/ht_s)^3$, where wt_t = weight of a tall person and ht_t = height of a tall person. Subscript "s" refers to a short person. The error inherent in ignoring body type was illustrated by the 1979 Build Study (25). When short and tall men were compared based only on height, it was found that short men had a higher mortality. However, further evaluation revealed that the short men were more overweight than tall ones. When tall and short men who were overweight to the same degree were compared, the short men had the lower death rate.

The age of the sample population can play a confounding role. For example, in the US, Hispanic and Native American males have higher mortality rates than whites until the ages 45 and 55, respectively. After these ages, their mortality rates drop significantly below those of whites and at 85 years of age, they have much lower death rates (59); *e.g.*, at ≥ 85 years, Native American males have less than 1/2 the mortality of white males (8,564/100,000 *vs* 18,261/100,000). Thus, if we track Hispanics, Asians and whites after 85 years of age, the whites will die off sooner and the Hispanics and Asians will have members who reach older ages than whites as demonstrated by California life tables (43). Also, almost half the US population lives longer than 75 years of age, and shorter people may have a reduced mortality after this age which would explain the greater longevity of short people described in this paper.

The use of 5- or 10-year cohorts may also have introduced errors in mortality studies such as Waaler's because groups of shorter men are generally older than taller ones (62). This condition can produce incorrect mortality rates especially at older ages; *e.g.*, for a 70–74 year cohort, short men would be grouped closer to the higher limit (74 years) of the cohort because more short men were born earlier in the century than tall ones. Tall men would be grouped closer to lower limit (70 years) of the cohort. This difference in age could result in an incorrect indication that short men have a 20 % to 40 % higher mortality rate.

To minimize the impact of SES and lifestyle factors, groups should be composed of people with similar backgrounds. Allebeck and Bergh (10) showed the importance of background similarity in comparing tall and short people. They found that short men were more likely to come from poor families and had a higher death rate than tall men. However, background analysis of the deceased men, found the higher mortality rate was due to a higher percentage of short men dying from suicides and injuries.

If Hispanic and Asian longevity findings are studied in isolation, the correlation with height could be accidental and not causally connected. However, height is a common denominator when viewed in the context of other studies which differed widely in ethnicity, diet and lifestyle. It thus appears to be causally connected to longevity, especially when the height/age slopes are compared as in Table 2.

Another confounder is early growth stunting due to malnutrition, illness or psychological and physical trauma. These early experiences can promote premature adult death and thus incorrectly suggest a causal connection with shorter stature. For example, rheumatic fever may damage the heart, retard growth and cause premature death in adulthood.

Secular growth and shrinkage can confound studies comparing the heights of young and elderly people; *e.g.*, the elderly are several centimeters shorter than young people. However, none of the studies in this paper made this comparison. Also, life expectancy comparisons between different ethnic groups and taller white or European contemporaries were not corrupted by shrinkage or secular growth because the ethnic groups were clearly shorter. Shrinkage of athletes studied was not a confounder because their heights were recorded during their youth.

Summary

The health and longevity of shorter, smaller people appears to be better than that of taller, bigger people based on extensive and consistent data on humans and animals. However, exceptions exist, such as corporate executives who have lower death rates than their employees (130). Regardless of height, people with BMI's of 20–22 appear to be at minimum mortality risk. Confounding factors play a role in virtually all studies and probably account for the wide range of conflicting findings from human mortality studies involving height, weight and BMI (Table 6).

While the scientific community is not ready to recommend putting children on extremely low energy diets, everyone probably agrees that a reduction in energy intake and improvement in types of food eaten would be beneficial, especially in view of recent findings by Cryan and Johnson (131) showing that our children are being overfed with energy intakes at least 20 % higher than what is considered optimal. While excess calories are undesirable, CR should not be implemented before 2 years of age or during pregnancy.

The findings of the WHO (2) and others (60) indicate that modern dietary practices play a major role in the incidence of many chronic diseases. Thus, energy, fat and animal protein intake needs to be reduced in developed countries. In view of the popularity of fast foods, it is unlikely that the public will voluntarily change to a diet consisting mainly of vegetables, fruits, legumes and grain products. However, the food industry has the ability to respond to changes in customer needs and can certainly remove much of the energy, fat, and protein from fast foods and desserts while retaining their nutrients, flavor and texture and increasing fiber.

We should also be more open to findings of scientists who have been warning us about the problems of feeding our children for maximum growth and development. Since WW I, the average American male has increased in height by 7 to 8 cm and in weight by over 18 kg. We need to ask ourselves what is the value of this trend and how is it affecting our world and humanity's chances for long-term survival.

A global population of shorter and lighter weight people can be a healthful and ecologically beneficial approach for a future world of 10 billion people. Affluent nations have made great progress in medicine and in reducing deaths from communicable diseases and infections. By combining these health benefits with less energy-rich food and smaller body size, additional improvements in our health and longevity can result (1, 3, 5).

In the near future, genetic engineering will allow parents to have the option to increase the height of their children. The current ideal Western height of 188 cm will continue to rise as the average height increases (132, 133). If the medical profession does not take a stand against promoting taller stature, the result will be a world of much taller and bigger people who will exacerbate current health, social and environmental problems (1, 134).

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