American Journal of Epidemiology
Vol. 150, No. 9
Printed in U.S.A.

Longitudinal Change in Height of Men and Women: Implications for Interpretation of the Body Mass Index

The Baltimore Longitudinal Study of Aging

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Age differences in height derived from cross-sectional studies can be the result of differential secular influences among the age cohorts. To determine the magnitude of height loss that accompanies aging, longitudinal studies are required. The authors studied 2,084 men and women aged 17–94 years enrolled from 1958 to 1993 in the Baltimore Longitudinal Study of Aging, Baltimore, Maryland. On average, men's height was measured nine times during 15 years and women's height five times during 9 years. The rate of decrease in height was greater for women than for men. For both sexes, height loss began at about age 30 years and accelerated with increasing age. Cumulative height loss from age 30 to 70 years averaged about 3 cm for men and 5 cm for women; by age 80 years, it increased to 5 cm for men and 8 cm for women. This degree of height loss would account for an "artifactual" increase in body mass index of approximately 0.7 kg/m^2 for men and 1.6 kg/m^2 for women by age 70 years that increases to 1.4 and 2.6 kg/m^2, respectively, by age 80 years. True height loss with aging must be taken into account when height (or indexes based on height) is used in physiologic or clinical studies. *Am J Epidemiol* 1999;150:969–77.

age factors; body height; body mass index; longitudinal studies

Height is a basic biologic characteristic known to change with aging. A large number of cross-sectional studies of age differences in height have been reported. For example, in 1950 Büchi (1) catalogued some 50 reports published between 1829 and 1947. While a number of studies have described the longitudinal rate of loss of height with aging (2), only seven covered the entire adult life span and in only three of these were there more than two height measurements per subject. A collation of 17 studies on longitudinal change in height with aging will be reported separately (2).

Any age-related change in height has implications beyond descriptive anthropometry. If height changes with age, indexes of obesity such as the body mass index (BMI; weight in kilograms divided by height in meters squared) would change with age independent of any change in obesity. Because BMI is related to the square of the height, even a small change in height may have a large effect on the BMI. Thus, a given BMI could have different meanings for adults at different ages, even if no other changes in body composition occurred with aging. Because height is lost with normal aging, it is important to quantify the effect the height "artifact" has on the computed BMI. Recent proposals of best weight for height suggest that a modest increase in BMI with age is related to optimum survival (3, 4). It is possible that the suggested magnitude of the BMI increase is no more than a result of the height artifact on BMI. To ascertain whether BMI should increase beyond the magnitude of the effect due to the age-related height artifact, the magnitude of the artifact must be determined.

To ascertain the pattern of adult height change as a function of age, to compare the patterns for men and women, and to examine the effect of height change with age on BMI, we analyzed data from the Baltimore Longitudinal Study of Aging (BLSA) (Baltimore, Maryland). This paper reports the results of cross-sectional and longitudinal analyses carried out for men and women across the entire adult span of years.

MATERIALS AND METHODS

Subjects

The subjects for this study were men and women aged 17–94 years when they joined the BLSA, an open

Received for publication October 9, 1997, and accepted for publication March 4, 1999.

Abbreviations: BLSA, Baltimore Longitudinal Study of Aging; BMI, body mass index.

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cohort study of normative aging (5). Men have been studied since 1958, women since 1978. Initially, men aged 70 years or younger were examined every 18 months, those over age 70 years annually. In 1970, the examination schedule was changed to every 2 years for men aged 20–59 years, every 18 months for those aged 60–69 years, and annually for those aged 70 years or older. Since 1978, all subjects have been examined every 2 years. BLSA subjects generally are well educated, middle to upper-middle class, community dwelling, and in good health. The present study reports on longitudinal analysis of height change with age for 1,068 men and 390 women and on cross-sectional height differences obtained for 1,430 men and 654 women. Because only 6 percent of BLSA participants are members of minority groups, and because the change in height with age may not be the same for different racial groups, these analyses were limited to White subjects. Throughout the course of the study, height was measured by using a movable anthropometer with subjects in their stocking feet. Subjects were asked to stand tall with heels together, head in a "normal" position, and eyes looking straight ahead. Data for this report were collected from 1958 through 1993.

Statistical methods

Cross-sectional data. The sex-specific cross-sectional age differences in height were quantified by regressing height on age using both linear and quadratic models. In these regressions, each subject was characterized by his or her mean height and mean age during participation in the study. In addition to these regressions based on data from all of the subjects, we tabulated age decade-specific mean heights.

Longitudinal data. Longitudinal analyses of the change in height with age included only those subjects whose height was measured three or more separate times. A two-stage random effects model was used to analyze the data. The first stage consisted of computing each subject's rate of height loss ($\beta_{Subject}$) by regressing the subject's heights on the ages at which the heights were measured, as follows:

$$\text{Height} = \beta_0 + \beta_{Subject}\text{Age}$$

The second stage began by characterizing each subject by $\beta_{Subject}$ and age at enrollment. The subjects were then assigned to one of nine age groups on the basis of their entry age: 17–19, 20–29, 30–39, . . . , and 90–94 years. Within each age group, the subject-specific slopes and entry ages were averaged to produce a decade-specific mean slope and a decade-specific entry age, as well as their associated standard errors. A two-stage random effects model allows for unbalanced and incomplete data. Each subject may have had his or her height measured a different number of times, resulting in unbalanced data. In the data series for any subject, data for one or more of the "scheduled" collections times may not have been obtained, resulting in incomplete data.

To quantify the rate at which the slope of height on age changes with age, sex-specific regressions were performed in which the subject-specific slopes of height on age ($\beta_{Subject}$ from the linear model above) were regressed on entry age in a quadratic model. The following quadratic equation was used:

$$\beta_{Subject} = \beta_0 + \beta_1(\text{Age} - \overline{\text{Age}}) + \beta_2(\text{Age} - \overline{\text{Age}})^2$$

where

$\beta_{Subject}$ = the slope of height on age for a specific subject
Age = the subject's age at entry to the study
$\overline{\text{Age}}$ = the sex-specific mean age of the subjects included in this study

This analysis quantifies the rate at which the slope of height on age (i.e., the velocity of height change, $\beta_{Subject}$) changes with age; it gives (through the coefficients β_1 and β_2) the acceleration or deceleration in the rate of height loss that occurs with aging.

The effect of initial height on the rate of height loss ($\beta_{Subject}$) was assessed by adding entry height to the sex-specific quadratic equations relating age to the velocity of height loss:

$$\beta_{Subject} = \beta_0 + \beta_1(\text{Age} - \overline{\text{Age}}) + \beta_2(\text{Age} - \overline{\text{Age}})^2 + \text{Height}_{\text{At entry}}$$

To enable the statistical significance of the coefficients of the quadratic models (both cross-sectional and longitudinal) to be interpretable, that is, to eliminate the colinearity of age and age^2, the regressions were performed by using "centered" terms for age and age^2 (6). Centering was accomplished by subtracting the appropriate sex-specific mean age from each subject's entry age prior to entering age or age^2 into the quadratic models.

The cumulative longitudinal changes in height of men and women that occur over the adult life span, from young adult life (e.g., age 20 years) to late life (e.g., age 80 years), were calculated by integrating, with respect to age, the equations relating the longitudinal slope of height to age:

$$\text{Cumulative height change} = \int \beta d\text{Age} = \int \beta_0 + \beta_1(\text{Age} - \overline{\text{Age}}) + \beta_2(\text{Age} - \overline{\text{Age}})^2 d\text{Age}$$

where dAge indicates that the integration is performed with respect to age.

The cumulative change in height was used to determine the change in BMI associated with loss of height, assuming weight remains constant:

$$\text{Change in BMI} = \text{weight}_{\text{initial}} \Big/ \left(\text{height}_{\text{initial}} - \int (\beta_0 + \beta_1(\text{Age} - \overline{\text{Age}}) + \beta_2(\text{Age} - \overline{\text{Age}})^2)\text{dAge}\right)^2$$

where
$\text{weight}_{\text{initial}}$ = the weight at the youngest age
$\text{height}_{\text{initial}}$ = the height at the youngest age

RESULTS

Cross-sectional

Among both men and women, cross-sectional height decreased with age (figure 1, table 1). The relation between age and height was curvilinear; a quadratic equation described the relation better than a linear equation did (for both men and women, partial *F* test $p < 0.02$). The curvilinear relation shows that height was lost at an increasing rate with increasing age. For men, age explained 14 percent of the variance in height (equation 1, appendix). For women, age explained 22 percent of the variance (equation 2, appendix). The coefficients for both men and women were significant at $p < 0.001$.

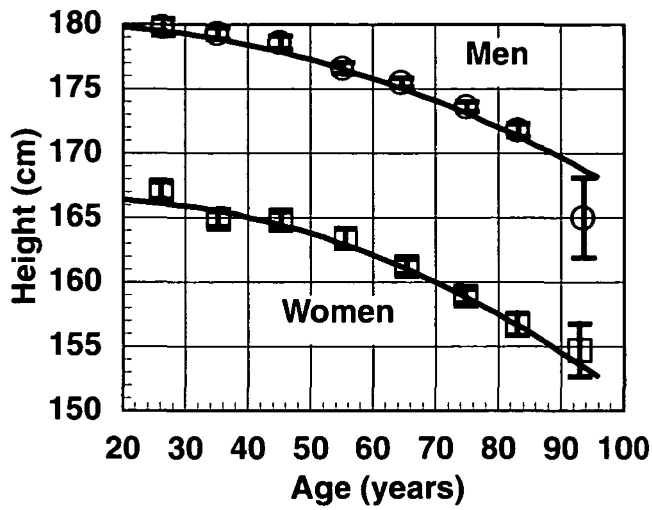

FIGURE 1. Cross-sectional differences in height with age among men and women from the Baltimore Longitudinal Study of Aging, Baltimore, Maryland, 1958–1993. The curves represent sex-specific cross-sectional equations derived by regressing data from 1,430 men and 654 women on age. The eight points plotted for each sex are the decade-specific cross-sectional means; the error bars represent plus or minus one standard error.

Longitudinal

A total of 1,068 men, aged 17–94 years (mean, 50.6) when they entered the BLSA, were followed for an average of 15 years (table 2). A total of 390 women, aged 17–93 years (mean, 53.5) at entry, were followed for an average of 9 years. The follow-up period ranged from 1.9 to 33.7 years. Subjects' height was measured three or more times. During follow-up, men had their height measured an average of nine times, women five times. Among both men and women, the longitudinal slope of height on age became increasingly negative with increasing age (table 2, figure 2), and the rate of loss of height increased with increasing age. In each age group except 90–94 years, where the sample size

TABLE 1. Cross-sectional relation between age and height among men and women in the Baltimore Longitudinal Study of Aging,* Baltimore, Maryland, 1958–1993

Age group (years)	Men				Women			
	Mean age (years)	No. of subjects	Mean no. of observations per subject	Mean height (SE†) (cm)	Mean age (years)	No. of subjects	Mean no. of observations per subject	Mean height (SE) (cm)
17–19	17.7	1	1	184.8	19.6	1	2	151.3
20–29	26.5	89	2	179.8 (0.66)	26.1	83	2	167.1 (0.66)
30–39	35.2	212	6	179.3 (0.45)	35.2	105	3	164.9 (0.61)
40–49	45.2	180	8	178.6 (0.51)	45.2	66	4	164.8 (0.66)
50–59	55.2	239	9	176.6 (0.43)	55.5	86	4	163.4 (0.74)
60–69	64.6	291	8	175.5 (0.35)	65.3	114	4	161.2 (0.58)
70–79	75.0	293	7	173.6 (0.38)	74.7	127	4	158.9 (0.56)
80–89	83.2	117	5	171.8 (0.49)	83.0	64	3	156.7 (0.86)
90–94	93.6	8	4	165.0 (3.09)	92.9	8	3	154.7 (2.06)
Total	57.6	1,430	7	176.1 (0.18)	56.0	654	4	162.2 (0.28)

* Subjects were assigned to an age group on the basis of their mean age during their participation in the study and were characterized by their mean height.
† SE, standard error.

TABLE 2. Longitudinal change in height with age among men and women in the Baltimore Longitudinal Study of Aging,* Baltimore, Maryland, 1958–1993

Age group (years)	Mean age (years) at entry	No. of subjects	Mean no. of height measurements per subject	Mean follow-up (years)	Mean height (cm)	Mean slope (SE†) (cm/year)	*p* value	Slope for women-men (SE difference) (cm/year)	*p* value
					Men				
17–19	18.4	6	5	13	180.8	0.106 (0.080)	0.25		
20–29	26.9	141	7	16	179.2	0.013 (0.006)	0.04	–0.018 (0.023)	0.43
30–39	34.8	202	9	18	178.9	–0.024 (0.006)	0.00	–0.002 (0.022)	0.93
40–49	45.3	206	12	21	176.7	–0.063 (0.005)	0.00	–0.047 (0.024)	0.06
50–59	54.8	167	10	17	175.1	–0.102 (0.009)	0.00	–0.063 (0.018)	0.00
60–69	64.9	147	9	12	174.2	–0.143 (0.011)	0.00	–0.080 (0.019)	0.00
70–79	73.9	155	7	8	172.8	–0.192 (0.013)	0.00	–0.098 (0.033)	0.00
80–89	82.3	41	5	5	171.1	–0.308 (0.038)	0.00	–0.164 (0.119)	0.17
90–94	93.4	3	5	5	167.6	–0.575			
Total	50.6	1,068	9	15	176.1	–0.091 (0.004)	0.00		
					Women				
20–29	26.4	46	4	8	166.7	–0.005 (0.022)	0.81		
30–39	35.1	70	5	9	164.0	–0.026 (0.021)	0.21		
40–49	44.4	46	6	10	165.1	–0.110 (0.024)	0.00		
50–59	55.0	63	6	11	160.7	–0.165 (0.015)	0.00		
60–69	65.0	71	6	10	160.6	–0.223 (0.016)	0.00		
70–79	74.2	78	4	7	157.5	–0.290 (0.030)	0.00		
80–89	82.8	12	4	6	154.3	–0.472 (0.113)	0.00		
90–93	91.7	3	3	4	157.7	–0.336	0.00		
Total	53.5	390	5	9	161.6	–0.161 (0.011)	0.00		

* Subjects were assigned to age groups on the basis of their age at first visit.
† SE, standard error.

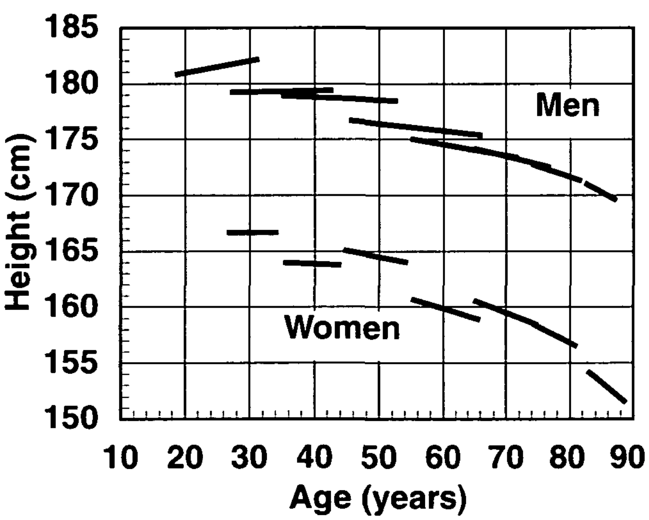

FIGURE 2. Longitudinal change in height, by decade of age, among men and women from the Baltimore Longitudinal Study of Aging, Baltimore, Maryland, 1958–1993. Each line segment starts at the point corresponding to subjects' mean entry age and height. The projection of each line segment on the abscissa represents the average follow-up period; the slope of each segment is the slope of height on age for each age group. Data for the oldest age group, 90–94 years, were not included because of the small sample sizes (table 2).

was very small, the slope was more negative for women than it was for men (table 2, figure 3), indicating that at all ages women lose height more rapidly than men do. The rate of loss was statistically significantly more rapid among women than among men in the age groups 50–59, 60–69, and 70–79 years. (In the age group 40–49 years, the rate of loss was more rapid among women than among men, $p < 0.06$.) The rate at which women lost height increased more rapidly with age than it did for men. Thus, the difference between the sex-specific slopes increased progressively from age 30–39 through 80–89 years (table 2). For both men and women, the slopes were significantly negative in the five decades of 40–49, 50–59, 60–69, 70–79, and 80–89 years.

Age explained 33 percent of the variance in the rate at which men's height changed (equation 3, appendix). For women, age explained 28 percent of the variance (equation 4, appendix). The coefficients of both equations were significant at $p < 0.001$. For men, the relation between age and the rate of change in height was curvilinear. An equation containing age and age^2, that is, a quadratic equation (equation 3, appendix), fit the data better than an equation linear in age (i.e., contain-

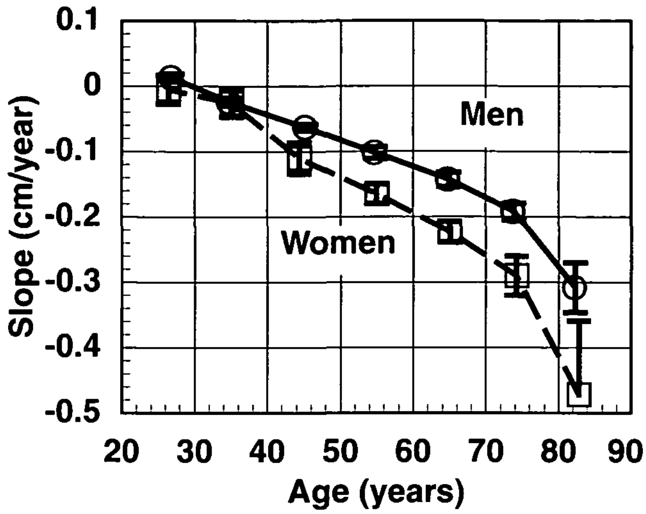

FIGURE 3. Comparison of the decade-specific slopes of change in height for men and women from the Baltimore Longitudinal Study of Aging, Baltimore, Maryland, 1958–1993. The error bars represent one standard error. The oldest age group of men and women, 90–94 years, and the youngest age group of men, 17–19 years, were not included because of small numbers of subjects observed (table 2).

ing age but not age^2; equation 5, appendix), $p < 0.001$. For women, there was a suggestion that the quadratic equation (equation 4, appendix) fit the data better than the linear equation did (equation 6, appendix), $p < 0.16$. The slope from the linear equation (equation 6, appendix) for women, –0.00654 (standard error, 0.00054) cm/year per year, was more negative than the slope from the linear equation (equation 5, appendix) for men, –0.00478 (standard error, 0.00021) cm/year per year, $p < 0.003$.

Rate of loss of height as a function of initial height

The rate of loss of height was a function of initial height for men but not for women; taller men lost height faster than shorter men did (equation 7, appendix). For men, the intercept and the coefficients of the linear and quadratic age terms in the equation (equation 7, appendix) were significant at $p < 0.001$, and the coefficient of the height term was significant at $p = 0.04$. The combination of age, age^2, and initial height explained 33 percent of the variance in the rate of loss of height (equation 7, appendix), the same proportion that was explained by using a model that contained only age and age^2 (equation 3, appendix). In an equivalent analysis for women, the coefficient for the height term was not significant at $p = 0.60$. Although initial height was a statistically significant predictor of the rate of height loss for men, the effect was relatively small compared with the effect of aging. The effect of initial height across the entire range of heights of BLSA males was to increase the rate of height loss 0.054 cm/year for the tallest compared with the shortest men. For men, the addition of initial height to the equation giving slope as a function of age made only minor changes to the value of the intercept and the coefficients of age and age^2. Thus, the effect of age on the rate of height loss was largely independent of the effect of initial height.

Cumulative loss of height over the adult life span

The cumulative longitudinal changes in height of men and women that occur over the adult life span, from young adult life (e.g., age 20 years) to late life (e.g., age 80 years), can be calculated by integrating, with respect to age, the equations that relate longitudinal slope of height to age (men: equation 8, appendix; women: equation 9, appendix). Evaluation of the sex-specific integrals for any two ages (e.g., 20 and 80 years) produces the difference between the heights at the two ages, the change in height that occurs over the 60-year period from age 20 to 80 years. The average aggregate loss of height over the adult life span is greater for women than it is for men (figure 4).

Change in BMI associated with loss of height

The changes in height that occur with aging can be used to determine the cumulative change in BMI with age due solely to the change in height, that is, under

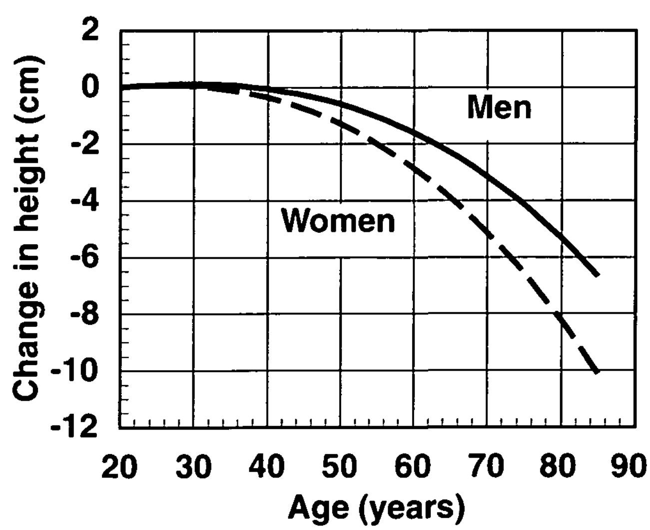

FIGURE 4. Average cumulative loss of height with aging for men and women from the Baltimore Longitudinal Study of Aging, Baltimore, Maryland, 1958–1993. The curves were created by integrating, with respect to age, the equations giving the sex-specific slopes of height as a function of age (described in Implications of loss of height for interpretation of the BMI) and evaluating the integrals from age 20 years to the ages shown along the abscissa.

the assumption that weight remains constant with age. The change in height with age had a substantial and increasing effect on BMI beyond middle age (figure 5). The results of our study demonstrated that in the 60-year period from age 20 to 80 years, BMI increased by an average of 1.5 kg/m^2 for men and 2.5 kg/m^2 for women (figure 5), independent of any change in weight.

DISCUSSION

Our results show that in the BLSA population, men and women lose height with age (cross-sectional analysis) and with aging (longitudinal analysis). The relation between height and aging is curvilinear for men (both the cross-sectional and longitudinal associations were statistically significantly quadratic) and somewhat curvilinear for women (the cross-sectional association was statistically significantly quadratic, and the longitudinal association was suggestive at $p < 0.16$), indicating that the rate of height loss increases with increasing age (figures 1 and 2). The increasing rate of height loss with aging is evident in the decade-specific longitudinal slopes of height on age (table 2), which become increasingly negative with increasing age. Women lose height more rapidly than men do; the sex difference is not significant cross-sectionally but is highly significant longitudinally. Interestingly, for women, the decline in height is almost identical in cross-sectional (–0.167 cm/year) and longitudinal (–0.161 cm/year) analyses. However, for men, the rate of decline is significantly larger in cross-sectional (–0.147 cm/year) than in longitudinal (–0.091 cm/year) analysis.

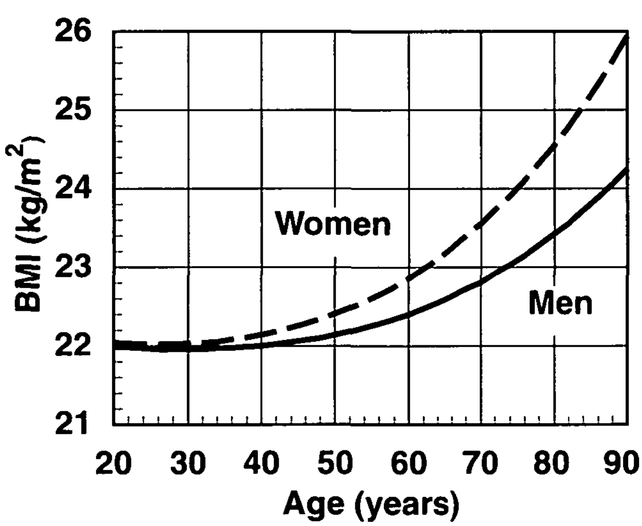

FIGURE 5. Average change in body mass index (BMI) associated with change in height (assuming constant weight) during adult life for men and women in the Baltimore Longitudinal Study of Aging, Baltimore, Maryland, 1958–1993. Loss of height associated with aging was computed by integrating the sex-specific longitudinal equations relating slope to age, resulting in equations that related height to age. The graphs were constructed by assuming a height of 175.3 cm and a weight of 67.6 kg for men and a height of 162.6 cm and a weight of 58.1 kg for women at age 20 years.

The equality for women and the inequality for men are consistent with a secular or cohort effect for men but not for women. Cohort differences in height must reflect influences during the earlier years of life (intrautero to the end of development). The reason that the BLSA men but not the women show this cohort effect is not clear. Several factors could contribute: 1) The sample size is smaller for women than for men; 2) changes in nutritional practices may have occurred differently for boys and girls; and 3) even though recruitment techniques were the same for the men and women in the BLSA study, it is possible that there were differences in the ethnic or cultural makeup of the men and women recruited over the years, but we are not aware of any such differences.

Implications of loss of height for interpretation of the BMI

The change in height associated with aging has implications for interpretation of the BMI, a commonly used index of adiposity. The rationale for "correcting" weight for height is obvious. BMI is generally assumed to be an age-invariant measure of obesity, that is, a given BMI at age 20 years is tacitly assumed to measure the same degree of obesity at ages 20, 30, . . . , and 90 years. Because BMI is inversely proportional to the square of height, even a small change in height might have a large effect on BMI. The change in height with age has a substantial and increasing effect on BMI beyond middle age (figure 5). In the 60-year period from age 20 to 80 years, BMI on average will increase by 1.5 kg/m^2 for men and 2.5 kg/m^2 for women (figure 5), independent of any change in weight. Therefore, the tacit assumption that BMI measures the same degree of obesity at all ages is incorrect. BMI values increase with age as height decreases, which could lead to an interpretation that obesity has increased. To our knowledge, the values shown in figure 5 represent the first attempt to quantify this artifact.

Although loss of height with aging has a substantial effect on BMI, the relatively minor quantitative effect on BMI of loss of height with aging on the interpretation of guidelines for best weight for height can be appreciated by comparing the height artifact with several published recommendations for optimal BMI at increasing ages. Table 3 presents the optimal BMI at specific ages and the BMI changes due solely to height loss for men and for women. From age 22 to 70 years, the optimum increase in BMI according to the

TABLE 3. Optimal BMI* values from several sources compared with BMI changes due solely to loss of height with aging, the Baltimore Longitudinal Study of Aging, Baltimore, Maryland, 1958–1993

	Age (years)					
	22	30	40	50	60	70
Recommended BMI						
Source of recommendation (reference)†						
Gerontology Research Center (5)	20.1	21.3	22.9	24.5	26.1	27.7
National Research Council (6)	21.5	22.5	23.5	24.5	25.5	26.5
Dietary Guidelines for Americans, 1990 (7)	22.0	22.0	24.0	24.0	24.0	24.0
Dietary Guidelines for Americans, 1995 (9)	22.0	22.0	22.0	22.0	22.0	22.0
Metropolitan Life Insurance Company (8)		22.4	22.4	22.4		
BMI changes due to height change						
Men	22.0	22.0	22.0	22.2	22.4	22.7
Women	22.0	22.0	22.2	22.4	22.9	23.6

* BMI, body mass index (kg/m²).

† The Gerontology Research Center, National Research Council, and Dietary Guidelines for Americans tables are not sex specific, that is, separate tables for men and women were not deemed necessary. In the Metropolitan Life Insurance tables, the BMIs at the midpoint for a medium frame are the same for men and women at their sex-specific average heights: heights were corrected for shoe height (1 inch for men and women; 1 inch = 2.54 cm), and weights were corrected for weight of clothes (5 pounds for men, 3 pounds for women; 1 pound = 0.45 kg).

Gerontology Research Center table (7) is 7.6 kg/m^2, while there is an artifactual increase in BMI of 0.7 kg/m^2 for men and 1.6 kg/m^2 for women due to a decrease in height (table 3). Similar computations show that the National Research Council (8) recommends an increase of 5.0 kg/m^2. The 1990 Dietary Guidelines for Americans (9) recommend an increase of 2.0 kg/m^2 at age 35 years, while the 1983 Metropolitan Life Insurance Company table (10) indicates that BMI should be constant from ages 25 to 59 years. Similarly, the 1995 Dietary Guidelines for Americans (11) do not recommend an increase in BMI with aging. The increase in weight recommended by both the National Research Council and the Gerontology Research Center is significantly larger than that attributable to the age-related loss of height alone.

If the denominator in the equation used to calculate BMI ($weight/height^2$) is decreased, the age-associated loss of height artifactually increases the BMI without increasing true adiposity. The artifact becomes important for men after age 50 years and for women 10 years earlier (figure 5). To our knowledge, this artifact has not been quantified previously. However, height is not the only aspect of body composition that changes with age. There is also loss of lean body mass (primarily muscle) and usually an increase in adipose tissue mass. The effect of these changes is to increase true adiposity (percent body fat). The effects of the loss of height and of lean body mass with aging are therefore opposite: height loss increases apparent obesity through an artifactual increase in BMI, while loss of muscle mass (with its consequent decrease in weight) makes older subjects appear less obese than they truly are. Thus, interpretation of any given BMI across the age span as it pertains to partitioning the body into fat and fat-free mass is complex, and a simple adjustment of the observed BMI for height loss will not make BMI an age-invariant measure.

Suggestions for future studies

Our study population was limited to White men and women, and we are unaware of any study of longitudinal change in height in non-White populations. Studies of non-White populations are clearly needed. During each BLSA visit, each subject's height was measured only once. Therefore, we have no data on the reliability of repeated height measurements, a limitation of our study that should be avoided in future studies. Of note, we recently completed a review of the world's literature describing longitudinal change in height (2). None of the papers we found provided data describing the reliability of repeated height measurements.

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APPENDIX

Equations, obtained from cross-sectional analyses, relating height to age:

Men:

$$\text{Height} = 178 - 0.1316(\text{Age} - 50.6) - 0.00151(\text{Age} - 50.6)^2;\ r^2 = 0.14, p < 0.001 \quad (1)$$

Women:

$$\text{Height} = 163 - 0.1635(\text{Age} - 53.5) - 0.00191(\text{Age} - 53.5)^2;\ r^2 = 0.22, p < 0.001 \quad (2)$$

Equations, obtained from longitudinal analyses, describing the relation between the rate at which height is gained or lost (i.e., the slope of height (β_{Subject})) and age:

Men (modeled as a quadratic relation):

$$\beta_{\text{Subject}} = -0.0784 - 0.00463(\text{Age} - 50.6) - 0.0000439(\text{Age} - 50.6)^2,\ r^2 = 0.33 \quad (3)$$

Women (modeled as a quadratic relation):

$$\beta_{\text{Subject}} = -0.1455 - 0.00660(\text{Age} - 53.5) - 0.0000476(\text{Age} - 53.5)^2,\ r^2 = 0.28 \quad (4)$$

Men (modeled as a linear relation):

$$\beta_{\text{Subject}} = -0.0912 - 0.00478(\text{Age} - 50.6),\ r^2 = 0.32 \quad (5)$$

Women (modeled as a linear relation):

$$\beta_{\text{Subject}} = -0.1605 - 0.00654(\text{Age} - 53.5),\ r^2 = 0.28 \quad (6)$$

Equation, obtained from longitudinal analyses, describing the relation between the rate at which height is gained or lost (i.e., the slope of height ($\beta_{Subject}$)) and age; the equation is adjusted for the initial height:

Men:

$$\beta_{Subject} = 0.13537 - 0.00479(\text{Age} - 50.6) - 0.0000443(\text{Age} - 50.6)^2 - 0.00121\text{Height}, \quad (7)$$

$$r^2 = 0.33, p < 0.001 \text{ for all coefficients except height, coefficient for height} = p < 0.04,$$

where Height is the subject's initial height in centimeters.

Equations, obtained from longitudinal analyses, describing the cumulative loss in height with aging:

Men:

$$\text{Cumulative height change} = \int -0.0784 - 0.00463(\text{Age} - 50.6) - 0.0000439(\text{Age} - 50.6)^2 d\text{Age} \quad (8)$$

$$\text{Cumulative height change} = 0.0435\text{Age} - 0.00009\text{Age}^2 - 0.000015\text{Age}^3$$

Women:

$$\text{Cumulative height change} = \int -0.1455 - 0.00660(\text{Age} - 53.5) - 0.0000476(\text{Age} - 53.5)^2 d\text{Age} \quad (9)$$

$$\text{Cumulative height change} = 0.0714\text{Age} - 0.00075\text{Age}^2 - 0.000016\text{Age}^3$$