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Estimating Actual Height in the Older Individual

REFERENCE: Galloway, A., **"Estimating Actual Height in the Older Individual,"** *Journal of Forensic Sciences,* JFSCA, Vol. 33, No. 1, Jan. 1988, pp. 126-136.

ABSTRACT: The widely used formulas for estimating adult stature require modification of the estimated height to account for the effects of age. The recording of measured and reported height in a living older population from southern Arizona, in conjunction with bone mineralization monitoring, provides an opportunity to test the currently used correction factor. Loss of height appears to commence around the age of 45, and the average rate of loss is relatively rapid at 0.16 cm per year. The correction factor suggested by this study is 0.16(age − 45), subtracted from the maximum height. The loss is also affected by the maximum height of the individual. In cases of low bone mineralization, the increased incidence of vertebral crush fractures may cause further reductions in standing height. The low rate of recognition of height changes among the older community lowers the usefulness of the age adjusted height estimate. It is recommended that both the maximum and age adjusted heights be provided in forensic science reports to aid in matching with missing person reports.

KEYWORDS: physical anthropology, human identification, musculoskeletal system, height estimation

Estimation of living height is an important part of the physical profile developed by forensic anthropologists from skeletonized or partly skeletonized remains [*1-11*]. The long bones, particularly those of the lower limb, provide excellent means of calculating a probable height once racial affinity and gender have been determined.

The loss of stature in the older individual has been recognized by anthropologists and other researchers interested in the aging process [*5,12*]. A formula for adjusting estimated height as calculated from long bones was developed by Trotter and Gleser and is now used extensively in the forensic science setting.

Maximum adult height in the United States has changed considerably throughout the past two centuries in response to improved nutrition and health care [*13-16*]. This secular trend may affect the rate of stature loss in the later years and necessitates a reevaluation of the formula on a more recent data set. This report concentrates on the loss of height from maximum with advancing age, the recognition of height decrease among an older population, and the relationship between height loss and bone mineral status.

Materials and Methods

This study includes 550 Caucasian individuals from southern Arizona, ranging in age from 50 to 92. Current stature was measured, and subjects were asked to report present and

Received for publication 4 March 1987; revised manuscript received 16 May 1987; accepted for publication 20 May 1987.

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maximal height information, in feet and inches, in a questionnaire. Single-beam photon absorptiometry on the radial midshaft indicated bone mineral status of all subjects.

All participants are volunteers in the long-term bone mineral monitoring study conducted by the Department of Anthropology, University of Arizona. The National Dairy Research and Promotion Board, under the National Dairy Council, provided research support. Informed written consent was given in accord with terms mandated by the Human Subjects Committee of the university.

The subjects included in this study are restricted to Caucasians over 50 years of age. Distribution by age and sex along with mean measurements by age group are given in Table 1. Only one scan per individual was included in this study. A number of southern Arizona populations were included. Since there are significant differences in age and sex distributions between the locations, it was necessary to combine them to provide adequate numbers of individuals at each age-sex group. Economic and lifestyle differences between the study populations account for some height loss variation in intergroup comparisons.

Principally subjects have been recruited from Sun City and Tucson. Many of these individuals are recent immigrants to Arizona, having moved here following retirement. The Sun

TABLE 1—*Means and standard deviations (in parentheses) by five-year age group are given for each of the height measurements used in this study.*

Age	*N*	Maximum Height	Reported Height	Actual Height	Height Loss	% Loss
			COMBINED SAMPLE			
50-54	9	164.4 (8.5)	165.4 (8.2)	163.9 (7.4)	−0.7 (2.0)	−0.46 (1.2)
55-59	19	162.9 (7.2)	162.3 (6.4)	160.6 (6.8)	−2.3 (2.0)	−1.42 (1.2)
60-64	69	166.0 (7.5)	165.5 (7.7)	163.0 (7.1)	−3.0 (2.6)	−1.78 (1.5)
65-69	125	166.5 (8.5)	165.6 (8.9)	163.0 (8.2)	−3.5 (2.4)	−2.12 (1.4)
70-74	146	166.7 (9.9)	166.9 (9.9)	162.8 (9.9)	−3.9 (2.9)	−2.34 (1.7)
75-79	117	166.0 (8.8)	164.0 (9.9)	161.0 (8.8)	−5.3 (3.3)	−3.18 (2.0)
80-84	50	166.5 (9.7)	166.4 (9.9)	160.5 (9.1)	−5.8 (2.6)	−3.45 (1.5)
85-89	13	159.5 (6.9)	162.6 (6.2)	154.0 (10.6)	−6.4 (5.5)	−4.04 (3.6)
90+	2	170.0 ...	169.0 ...	166.0 ...	−4.1 ...	−2.38 ...
Total	550					
			FEMALES			
50-54	8	162.4 (6.7)	162.0 (3.6)	161.8 (6.3)	−0.60 (2.4)	−0.50 (1.3)
55-59	17	161.0 (5.9)	162.3 (6.4)	158.9 (5.6)	−2.14 (2.0)	−1.42 (1.2)
60-64	57	164.1 (6.3)	163.5 (6.1)	161.3 (6.0)	−2.84 (2.7)	−1.67 (1.6)
65-69	94	163.1 (5.8)	161.8 (6.2)	159.7 (5.9)	−3.38 (2.4)	−2.07 (1.4)
70-74	100	161.6 (6.1)	161.6 (6.1)	157.8 (6.3)	−3.85 (2.7)	−2.38 (1.7)
75-79	86	162.1 (5.8)	159.2 (6.3)	157.2 (6.3)	−5.08 (3.4)	−3.13 (2.1)
80-84	33	161.2 (5.4)	159.7 (6.1)	155.5 (4.8)	−5.65 (2.7)	−3.48 (1.5)
85-89	12	158.7 (6.4)	160.5 (5.6)	150.5 (9.5)	−7.03 (6.2)	−4.49 (4.0)
90+	2	170.0 ...	169.0 ...	166.0 ...	−4.05 ...	−2.38 ...
Total	409					
			MALES			
50-54	1	179.0 ...	179.0 ...	178.7 ...	−0.30 ...	−0.17 ...
55-59	2	175.5 (0.7)	... ...	173.0 (3.2)	−2.55 (2.5)	−1.46 (1.4)
60-64	12	173.9 (5.9)	176.8 (6.2)	170.2 (6.8)	−3.73 (1.5)	−2.25 (0.9)
65-69	31	177.0 (6.8)	177.1 (5.2)	172.9 (6.3)	−4.04 (2.2)	−2.27 (1.2)
70-74	46	177.6 (7.5)	177.6 (7.2)	173.5 (7.6)	−4.06 (3.2)	−2.27 (1.8)
75-79	31	177.2 (5.5)	176.4 (5.6)	171.3 (6.1)	−5.86 (3.2)	−3.31 (1.7)
80-84	17	176.5 (7.7)	176.0 (4.9)	170.5 (6.8)	−6.00 (2.5)	−3.38 (1.3)
85-89	1	170.0 ...	... ...	165.3 ...	−4.70 ...	−2.76 ...
90+	0	... ...	... ...	... ...	... ...	... ...
Total	141					

City group, mean age of 71.7, are active, affluent and ambulatory. Most participate in some exercise program or recreational sport and make extensive use of biomedical resources. The Tucson group has been studied in connection with a general health survey of residents of city public housing. They are much less affluent, more sedentary, and more prone to serious chronic debilitating illnesses. The mean age of this group is 72.3. Both groups are being studied under a mixed longitudinal research design with examinations repeated annually. A third group included in this report is from three rural communities in Arizona. Subjects were recruited through the Pinal County Health Department's exercise program and include long-term residents as well as recent immigrants to the area. The mean age of this group is 67.4 years. In addition, a small number of individuals were not involved in a formal program. Most of these were recruited from the university community.

A sample of 80 individuals, not included in the initial analysis of these data, was reserved as a test population for comparison of newly derived height estimation formulas with those commonly in use. This group consisted of recently scanned subjects from Casa Grande and Tucson.

Before measurement, subjects were asked to report their present height and their height at age 25, which was presumed to be their maximum adult height. Standing height measurements were obtained with a Gneupel freestanding anthropometer. The subjects' shoes were removed before height was measured. Individuals with severe back deformations were measured at the maximum standing height to which they could stretch. Standing height was used in preference to measurement in the supine position because it is more comparable to other measurements upon which the individuals would base reported heights.

Bone mineral assessment was conducted using a Lunar Radiation SP1 single-beam photon absorptiometer with an Iodine 125 source. The measurement was taken at the 1/3 distal site of the radius, determined by measuring the distance from the olecranon process to the styloid process of the ulna. Four passes were taken for each scan, corrected for edge placement and averaged. The following results are provided: (1) bone mineral content (BMC), calculated as grams of mineral per centimetre; (2) bone width (centimetres); and (3) bone mineral index (BMI), computed as grams per square centimetre from the two previous measurements providing an approximation of density. Replicability of this technique has already been well established with accuracy of 2 to 4% and precision of about 1% [*17,18*].

The data were analyzed using SPSS-PC Plus (Statistical Package for Social Sciences) [*19,20*] on an IBM PC-AT. Descriptive statistics were generated for all variables by five-year age group by sex. Linear regression analyses were conducted to determine relationships between variables and analyses of variance (ANOVA) were used to discriminate significant differences (SDs) between the subgroups used.

Results

The reported height at age 25 among women shows a slight secular increase of 1.2 cm per decade ($p = 0.02$). Among males, no secular change is observed ($p = 0.98$). Mean height for women is 162.3 (SD 6.01) cm and the means range from 164.1 cm for women born around 1920 to 1925 to 158.7 for those born about 1900. Two women, now in their nineties, were 170 cm at their tallest. Mean height in males is 176.9 (SD 6.76) cm. The mean height is greatest for men in the 70-to-74-year age group at 177.6 cm and shortest for men in the 60-to-64-year age group at 173.9 cm.

The reported current height matches well with the maximum height. The mean reported current height for women is 161.3 cm, 1 cm less than the average maximum height. For men the reported current height is 176.9 cm, exactly equal to the reported maximum height. The difference between the reported current height and maximum height rarely exceeds 1 cm (1/2 in.).

The actual height as determined by the anthropometer is well below both the maximum height and the reported current height. The mean height for women is 158.4 cm (SD 6.42) and for men it is 172.3 (SD 6.78). Comparison of reported current, maximum, and actual height is presented in Fig. 1.

Mean height loss by 5-year age group from age 50 to age 90 is given in Fig. 2. As can be seen, there is a progressive loss of height in both sexes ($r = 0.3713$). The rate of loss is slightly higher in males (mean −4.62, SD 2.9) than in females (mean −3.98, SD 3.1). In both groups there is a relatively steady loss of height throughout the years.

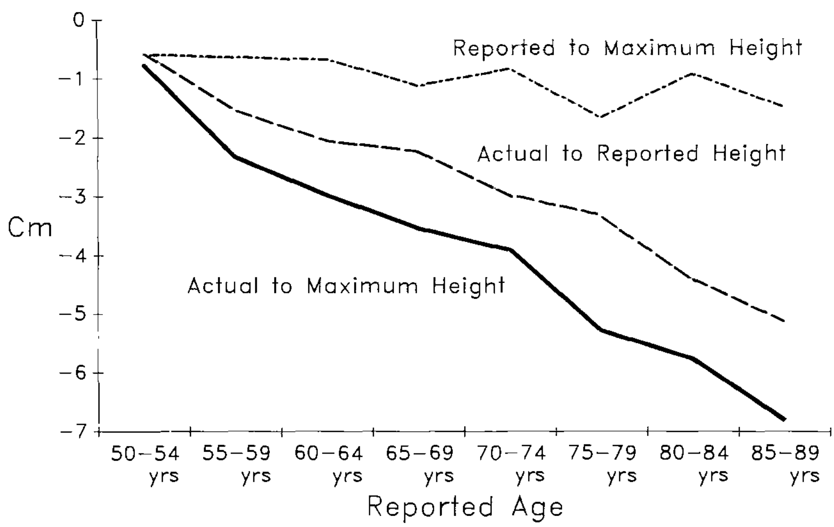

FIG. 1—*Discrepancies in mean reported maximum, reported current, and actual heights by five-year age groups.*

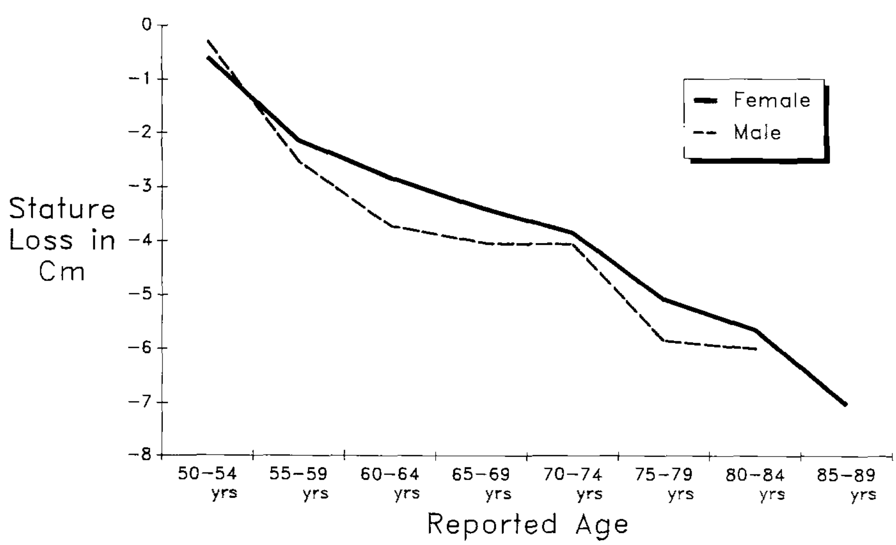

FIG. 2—*Mean stature loss in centimetres from reported maximum height by five-year age groups by gender.*

The total loss of height correlates with maximal height ($r = -0.1631, p = 0.0002$). Taller people tend to lose more height than shorter people, as is evident when height loss is expressed as a percentage of maximum height (Fig. 3). Stepwise multiple regression analyses also suggest that the maximum height plays an important role in the amount of height lost, though secondary to age.

When the study population is divided by maximum reported height, a steady increase in mean loss of height in centimetres can be observed (Fig. 4). Individuals ($n = 115$) who re-

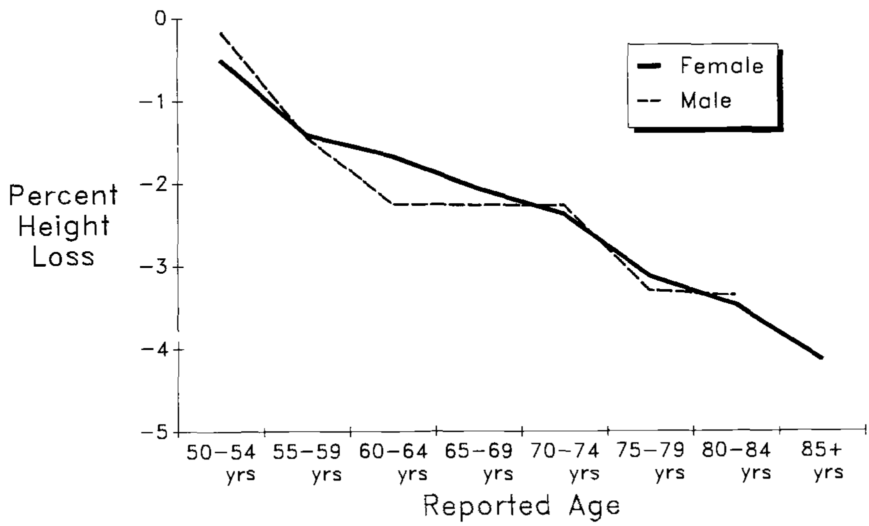

FIG. 3—*Mean stature loss expressed as a percentage of reported maximum height by five-year age groups by gender.*

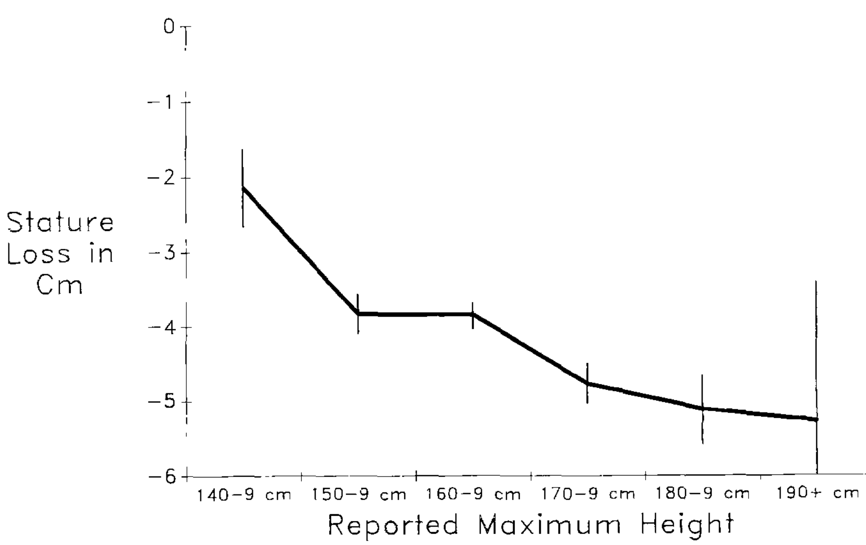

FIG. 4—*Mean stature loss in centimetres by the reported maximum heights, male and female samples combined. Standard error is indicated by vertical bars.*

ported maximum height of 140 to 149 cm lost an average of 3.83 cm (SD 3.1), while those 180 to 189 cm at their tallest ($n = 42$) lost 5.12 cm (SD 3.3).

Analysis of variance using a percentage of height loss showed no difference between males and females ($p = 0.3541$). The differences apparent when absolute height loss is measured are due largely to the height differences between the sexes. Data on males and females were merged in subsequent analysis.

Bone mineral content correlates significantly with the percentage of height loss from maximum ($r = 0.1055$, $p < 0.01$), and the bone mineral index strongly correlates with both the percentage and absolute values for height loss ($r = 0.1888$ and $r = 0.1433$, respectively, $p < 0.001$). Those with lower bone mineral status tended to lose more height (Fig. 5). The mean values show that most of this loss comes from those with extremely low values (BMI < 0.4) who lost an average of 6.61 cm (SD 4.7). The individuals with higher bone mineral values all showed mean values of between 3.4 and 4.9 cm loss.

Discussion

The lack of a noticeable secular trend in the study population is not surprising. A cessation in the secular trend toward increased height has already been suggested by previous studies [*13-15*], occurring in the early years of the twentieth century. Only the oldest individuals in the present study would have grown up at the end of the secular increase period. Taller people may be preferentially represented in the older age groups, reflecting better survival rates. Such individuals tend to have larger bone structure and, consequently, better bone mineral values. This would result in less susceptibility to hip and vertebral fractures, both major causes of mortality and morbidity in the later years [*21-23*]. Those people who achieved greater height may have done so as a consequence of economic advantages, which also affected overall survivorship.

The recognition of height loss among those individuals over age 50 tends to be minimal as is seen in the close matching of current reported height values and those reported as maximum height. At most, the impression of height reduction due to age is a decrease of about

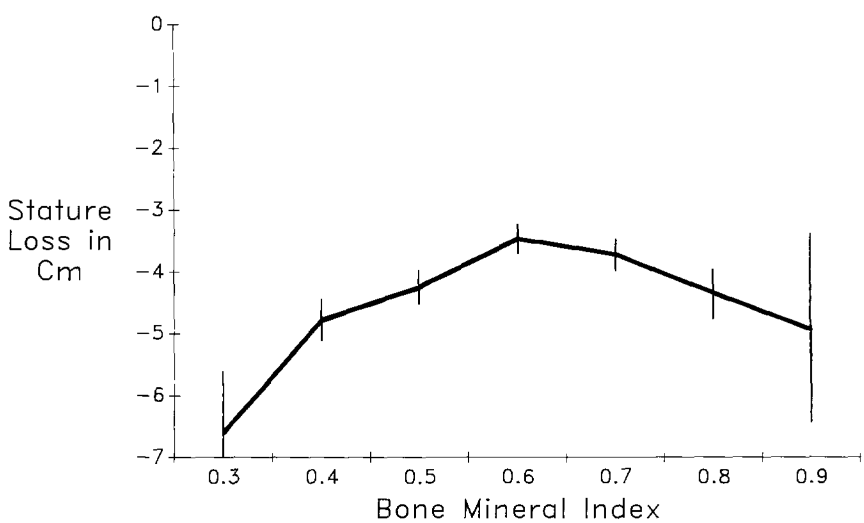

FIG. 5—*Mean stature loss in centimetres by the bone mineral index (BMI) at the 1/3 distal radial site. Standard error is indicated by vertical bars.*

1 cm. Reports of height on documents completed once stature loss has commenced are, therefore, frequently erroneous.

Errors in reported heights have been documented in other studies [*24–27*]. These show that shorter people tended to overreport their height while taller individuals may underreport. Himes and Roche [*25*] found about a 1-cm difference in reported and actual height for women. If the reported heights used in this study follow this trend, then the differences between the average height lost by short versus tall individuals would be even further exaggerated. Willey and Falsetti [*27*] also caution about serious underreporting of height seen among young adults whose last measurement occurred prior to completion of adolescent growth. Because of the possibility of serious reporting errors, actual height and reported current height were compared on a group of individuals younger than age 50 (n = 30). Discrepancies clustered at less than 1 cm with equal over- and under-reporting, suggesting that the reduction from maximum reported height seen in this study cannot be attributed solely reporting error.

Since the recognition of loss of adult height is not common, the examiner of skeletal remains should report the estimated maximum adult height as well as the height corrected for the estimated age of the individual. Individuals continue to report height closer to maximal than to actual height on vital documents, such as driver's licenses and hospital admission's records, which may be used in composing physical descriptions. Maximal height may, therefore, be more easily matched to a missing person report.

The loss of height, except when accompanied by kyphosis, seems to be mostly caused by factors other than changes in the bones. The most likely cause is compaction of the intervertebral disks, which normally compose 20 to 30% of the spinal length. With age, there are changes in the texture, structure, and physiology of the disk which result in compression and a loss in flexibility and strength. Comparison of loss of standing and sitting height by other studies [*28*] suggest that spinal changes are responsible for almost all the loss in maximum height.

Those who are the tallest presumably have a larger amount of their height composed of intervertebral disks. Therefore, the absolute loss in these individuals is greater than that seen in shorter individuals. The sex differences seen are largely due, not to sexual differences in the patterns of height loss, but to the tendency for smaller body size among females.

The longitudinal studies in Sun City and Tucson [*29,30*] allow for correlation of annual height loss with corresponding loss in bone mineral status. These show, as is evident in the present study, a correlation of height loss and low bone mineral status. This is probably due to the higher incidence of vertebral fractures in individuals with low bone mineral. These produce the condition commonly known as "dowager's hump" in which the thoracic spine becomes increasingly kyphotic and the lumbar area loses the normal lordosis.

In this study, the extremely large reduction in height among those individuals who have low bone mineral values, primarily women, is probably due to varying numbers of vertebral fractures. Some of these may cause obvious deformity, but many may be microfractures which will be difficult to observe even radiographically. While spinal fractures are common in individuals with loss of cortical bone [*31*], there are other factors which determine bone strength, altering the correlation of these features. The observation of abnormally thin cortical bone in skeletal material encountered in the forensic science situation should suggest the possibility of additional height loss as a result of vertebral fractures.

Trotter and Gleser [*5*] recommend an adjustment for the effects of aging on stature. The formula they propose is 0.06(age − 30), subtracted from the height calculated from long bones. This is based on the measurement of 855 cadavers from the Terry collection. The authors readily admit that there is a strong secular trend in the stature in the collection for which they attempted to compensate.

A major problem with the use of the Terry collection in this context is the lack of data on the maximum height of the older individuals. Trotter and Gleser estimated this from data generated from their younger military sample. The age of 30 years was arbitrarily chosen as the onset of the decline in stature. The height adjustment formula, therefore, is based largely on an assumption of age at onset.

The regression formulas conducted as part of the present study strongly suggest that the major decline in stature does not begin until about the age of 45. Once this loss of height commences the rate is fairly rapid. The mean annual loss is 0.1592 cm per year (Fig. 6) and is similar in males (0.172 cm/year) and females (0.155 cm/year). This is in general agreement with the findings of Friedlaender and colleagues [28] who saw the first significant decline in height in their 40- to 44-year-old cohort during a longitudinal study. Reevaluation of their data also shows an annual loss in healthy white men of 0.156 cm per year.

Calculation of estimated height in the older individual, therefore, can be best approximated by

$$\text{Height loss (cm)} = 0.16(\text{age} - 45)$$

As a consequence of the many factors involved in loss of height, the standard deviation is 3.7 cm, similar to that computed with the Trotter and Gleser formula. Since this present formula is derived on a living population, it should now be tested on a well-documented skeletal series.

Comparison with the formula proposed by Trotter and Gleser and the above formula on an independent sample of 80 individuals shows that both provide relatively good approximations of actual height until age 70, particularly among females. Beyond age 70, the Trotter and Gleser calculation tends to overestimate the actual height by 1.5 cm or more (Fig. 7). This discrepancy is enhanced by the increasing incidence of vertebral crush fractures in the older age groups.

No simple formula can estimate the actual height with complete accuracy since there are a multiplicity of factors which are involved. The pattern of height change (Fig. 6) shows a period of accelerated height loss during the fifties and early sixties. Later this tends to slow, but accelerates again in the late seventies and eighties. Two processes of height loss may be evident in this change in rates. The initial loss may be due to compression of the intervertebral disks because of changes in structure and support which may coincide with some vertebral fractures as a result of postmenopausal bone loss. The later changes are probably due to

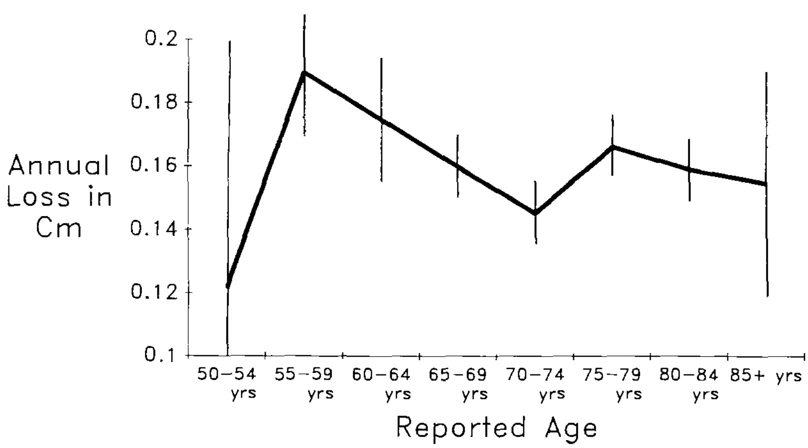

FIG. 6—*Mean annual stature loss in centimetres by five-year age groups. Standard error is indicated by vertical bars.*

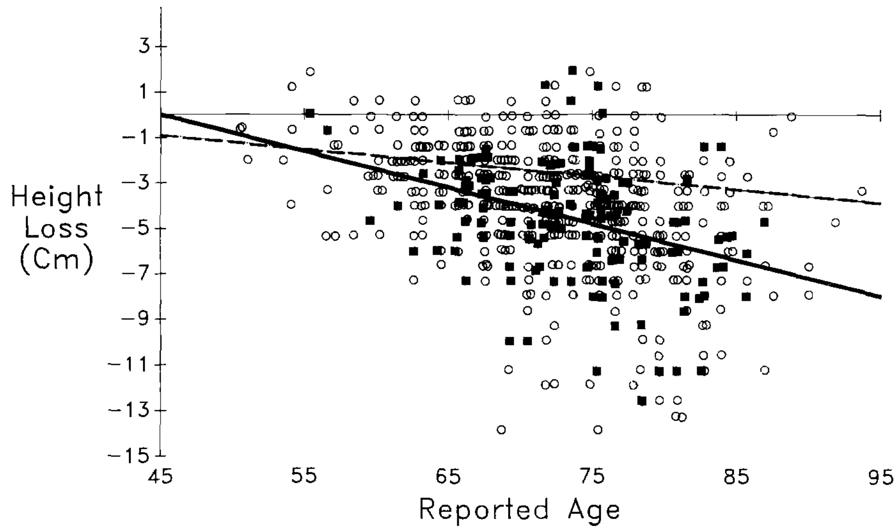

FIG. 7—*Comparison of the newly proposed formula* (solid line) *and the Trotter and Gleser (1951) formula* (dashed line) *shown in relation to the scatterplot of the data sample for height loss in centimetres from ages 45 to 95. Males are indicated by filled squares, females by circles.*

the higher incidence of major vertebral compression fractures attributable to age related bone loss, producing visible deformity of the spine.

As techniques for estimating age improve and as the older portion of the population increases, a means of more accurately estimating actual height in the old and very old individual will become more important to the forensic scientist. The adjustment provided here may help to improve these estimates by minimizing the errors as a result of rate of loss in the older age groups.

Conclusion

Height loss beyond the age of 50 depends on a number of factors, including original height and bone mineral status. Age is, however, the overriding component in determining actual height. The loss of height can be expected to begin about age 45 and continue relatively steadily throughout the rest of the life of the individual. This loss can best be calculated from maximum height by the formula 0.16(age − 45). In reporting height, the forensic anthropologist should be careful to include the estimated maximum height as well as age adjusted height, since recognition of height loss among the older population is not common. Finally, low bone mineral status raises the possibility that vertebral fractures may have further reduced standing height.

Acknowledgments

The data were collected during a long-term bone mineralization program through the Department of Anthropology, University of Arizona, under the direction of Dr. William A. Stini, whose guidance and support is gratefully appreciated. Funding has been provided by the National Dairy Research and Promotion Board, National Dairy Council. I would like to thank the research assistants of the program: Richard Harrington, Sherry Fox, and Pat Stein. The Volunteer Office of Boswell Memorial Hospital, the AgeWell Project and Pinal County Health Department provided valuable assistance in scheduling and data collection.

Much gratitude is owed to Mr. Charles Miksicek for editorial and statistical help and to Mr. Walter Allen for computer support. Finally, I would like to express my appreciation to the men and women who volunteered their time and wracked their memories for this research.

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