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Accuracy of Equations for Predicting Stature From Knee Height, and Assessment of Statural Loss in an Older Italian Population

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We determined the applicability of deriving the stature from knee height in an older Italian population, and, in the same population, we assessed longitudinally the change in stature over a 6-year interval. The standing stature and knee height in a supine position were measured in the entire home-dwelling older (65+ years) population of a small Italian town ($N = 606$). Stature measured in 1989 and in 1995 was used to assess longitudinal changes in 258 subjects of the same population. Stature derived from knee height was greater than measured stature in this population and in the two sexes. This difference disappeared when subjects with evident kyphosis were excluded. From 1989 to 1995, stature decreased by 1.7 ± 3.0 cm, with women showing a larger decrement than men. Stature estimated from knee height is more accurate than measured stature in subjects with kyphosis. In accordance with previous studies, stature decreases with aging, and such height loss is greater in women than in men.

MEASUREMENT of stature is of primary importance in the clinical examination of the individual patient, as well as in epidemiological surveys, since it is an essential parameter in assessing body composition. Moreover, stature, alone or in combination with body weight, is used to correct several structural and functional cardiovascular parameters. Therefore, the accuracy of its estimate may influence, in turn, the accurate estimate of these parameters. Although obtaining an accurate measurement of stature is substantially simple in the young adult population, this is not always possible in older people. In fact, older individuals are often unable to stand, since they may be chair- or bed-bound, or may present with spinal deformity and loss in vertebral height (1) that determine a disproportionate loss of height, resulting in an incorrect stature measurement. In this population, it may be more appropriate to estimate stature from measurements of other skeletal segments. In actuality, knee height shows the strongest correlation with stature (2–4). It should be taken into account that equations predicting height may substantially differ according to the race of the study population (5), although it is unknown whether differences in such equations arise from measurements of knee height in populations of a primarily identical racial group that live in different geographic areas and present only minor ethnic differences.

An age-associated decrement in body height has been reported by both cross-sectional studies, which may be influenced by the birth cohort effect (6), and longitudinal studies (7–9). The latter confirmed that this phenomenon is the result of an actual decrement in stature along with aging, but the entity of this change was not homogeneous across published series.

The first objective of the present analysis was to determine the applicability and accuracy of formulas previously proposed to derive stature from knee height in an Italian elderly population and verify whether kyphosis of the spine may influence the accuracy of such predictive formulas. The second aim of the analysis was to assess longitudinally, in the same population, the change in stature over a 6-year interval. To address these issues, we carried out a secondary analysis of a database from a two-wave, population-based, epidemiological survey of an older Italian cohort.

Methods

Study Population

In 1989, the Department of Gerontology and Geriatrics of the University of Florence and the Geriatric Department of the National Institute for Research and Care of the Elderly, Florence, Italy, carried out the first epidemiological study of the demographic characteristics and social and health status of an elderly (aged ≥65 years) population living in Dicomano, a small town near Florence (10). In 1995, a second epidemiological survey (*Insufficienza Cardiaca negli Anziani Residenti a Dicomano, ICARe Dicomano*), whose general design has been detailed elsewhere (11), was carried out in the same population to identify the clinical characteristics of heart failure in elderly individuals. All 864 (373 men and 491 women) home-dwelling residents aged 65 years and older, out of 4749 total residents, were eligible for the study. Of these, 614 subjects (71.1% of the eligible study population) underwent the clinical examination and cardiopulmonary assessment of the study protocol and have been included in the present analysis. All participants provided written informed consent.

The reasons for nonparticipation were as follows: 229

(26.5%) subjects refused to participate, 18 (2.1%) had died, two (0.3%) had moved to a different town, and one (0.1%) had been admitted to a nursing home before enrollment. Because two subjects (of 614, or 0.3%) were unable to stand and knee height data were missing in six subjects (of 614, or 1.0%), the present analysis comprises 606 subjects (253 men and 353 women, 70.1% of the eligible population).

Physical examinations, including history and physical findings, were carried out by five physicians, three of whom were fellows, trained in geriatric medicine, specifically the Division of Gerontology and Geriatrics of the University of Florence.

To assess the longitudinal changes in body height, the stature of 258 subjects (114 men and 144 women) enrolled in both the first (1989) and second (1995) phase of the study was analyzed. For all these subjects, the age reported in the present analysis was calculated in 1995.

Anthropometric Measurements

The stature of barefooted subjects standing upright against a wall was obtained using a vertical steel measurement bar, with the subject's head positioned according to the Frankfurt plane (i.e., with the lower margins of the orbital openings and the upper margins of the auditory meatus lying in the same horizontal plane). The distance between the occiput and the wall was also measured with subjects standing in the same position. In this phase, presence of clinically evident kyphosis was also recorded.

The knee height of barefooted subjects was measured in the supine position with ankle, knee, and tibia-tarsus joints flexed at 90°, using a SECA model 209 caliper (Vogel and Halke, Germany), with a fixed bar placed along the lateral tibial condyle and the lateral malleolus, and a moving component placed on the upper face of the thigh. All measurements, rounded to the nearest centimeter, were taken by two physicians only, who were unaware of the 1989 measurements. For each subject, measurements were made by the same physician and they were repeated until two identical results were obtained in a row.

To derive the stature from knee height, the following equations developed by Chumlea and Guo (12) for Caucasian men and women were used:

$$\text{Men: stature (cm)} = 59.01 + (2.08 \times \text{knee height [cm]})$$

$$\text{Women: stature (cm)} = 75.00 + (1.91 \times \text{knee height [cm]}) - (0.17 \times \text{age [years]}).$$

Statistical Analysis

Data were analyzed using the SPSS (SPSS, Inc., Chicago, IL) (13) statistical package and are reported as mean ± standard deviation (*SD*). Mean values were compared using Student's *t* test or analysis of variance followed by a post hoc test (Tukey's multiple comparison test). Age-associated changes in stature and knee height, as well as the correlation between predicted and measured stature, were analyzed by simple linear regression models. The independence of associations was assessed by stepwise multiple regression models. Comparisons between data collected in the two study phases were performed using the *t* test for paired observations. A *p* value $<.05$ was considered statistically significant.

Results

The mean age of the 606 subjects analyzed in the second phase (1995) of the study was 73 ± 6 years (mean ± *SD*), and ranged from 65 to 94 years. In the same subjects, stature was 157 ± 9 cm, and knee height was 49 ± 3 cm. Stature and knee height were obviously lesser in women than in men (152 ± 7 cm vs 165 ± 7 cm, $p < .001$, and 47 ± 2 cm vs 51 ± 3 cm, $p < .001$, respectively), and they were both inversely related with age (women's stature [cm] = 178.6 − 0.3625 age [years], $r = -.35$, $p < .001$; women's knee height [cm] = 51.6 − 0.0584 age [years], $r = -.15$, $p < .01$; men's stature [cm] = 193.2 − 0.3848 age [years], $r = -.36$, $p < .001$; men's knee height [cm] = 60.1 − 0.1175 age [years], $r = -.26$, $p < .001$). Also, when subdivided into three age groups (65–74, 75–84, and ≥85 years), men were taller than women within each group (Table 1). Stature was different among the three age groups for both men ($F = 18.97$, $p < .001$) and women ($F = 23.41$, $p < .001$) and was greatest in the youngest age group. Conversely, in both sexes, stature did not differ between the intermediate and the oldest age group. In general, age- and sex-associated changes in knee height paralleled changes observed for stature, with women exhibiting a less marked age-associated decrease in knee height (Table 1).

Stature estimated from knee height according to Chumlea and Guo's (12) method was 158 ± 8 cm in the entire subject population (166 ± 6 and 153 ± 5 cm in men and women, respectively). These values were greater than those actually measured in the subject population ($p < .001$) or in the two sex groups ($p < .001$ for both men and women). The average difference between estimated and measured stature was 0.98 ± 4.08 cm. This difference was positively correlated with age ($r = .16$, $p < .001$) and with the occiput-to-wall distance ($r = .29$, $p < .001$) and was similar in the two sexes. Of note, the occiput-to-wall distance was greater in men than in women (8.0 ± 3.0 cm vs 7.0 ± 3.1 cm, $p < .001$). However, multiple regression analysis (multiple $r = .30$, $p < .001$) demonstrated that only the occiput-to-wall distance and age were independently associated ($p < .001$ and $p < .05$, respectively) with the difference between estimated and measured body height. The measured stature of the 313 subjects without clinically evident kyphosis was similar to their stature as estimated from knee height, although in the 293 subjects with kyphosis, the measured stature was significantly lower than the estimated stature (Table 2). The correlation coefficients between predicted and measured height were $r = .89$ and $r = .91$, respectively, for subjects with and without kyphosis ($p < .001$ for both). The difference between estimated and measured stature was correlated with age only in the group with kyphosis ($r = .17$, $p < .005$).

Of the 606 participants in 1995, 193 had not been assessed in 1989, since at that time they were younger than 65 years. Of the remaining 413, only 258 had data from both points in time, because the other 155 participants either had refused to be visited in 1989 or had moved to the Dicomano area during the 6-year time interval. As expected, the stature of the 258 participants in both phases of the study decreased significantly over the 6-year interval, from 158 ± 9 cm in 1989 to 156 ± 9 cm in 1995 ($p < .001$). This difference

Table 1. Stature and Knee Height in Different Age Groups (phase 2, 1995)

	Group 1 (65–74 years)	p Value (Group 1 vs Group 2)	Group 2 (75–84 years)	p Value (Group 2 vs Group 3)	Group 3 (≥85 years)	p Value (Group 1 vs Group 3)
Stature (cm)†						
Men	167 ± 6 (n = 168)	<.001	162 ± 7 (n = 66)	NS	160 ± 5 (n = 19)	<.001
Women	154 ± 6 (n = 232)	<.001	149 ± 7 (n = 98)	NS	147 ± 6 (n = 23)	<.001
All	159 ± 9 (n = 400)	<.001	154 ± 9 (n = 164)	NS	153 ±9 (n = 42)	<.001
Knee Height (cm)†						
Men	52 ± 3 (n = 168)	<.001	50 ± 2 (n = 66)	NS	50 ± 3 (n = 19)	<.05
Women	48 ± 2 (n = 232)	<.05	47 ± 3 (n = 98)	NS	46 ± 3 (n = 23)	NS
All	49 ± 3 (n = 400)	<.001	48 ± 3 (n = 164)	NS	48 ± 3 (n = 42)	<.05

Notes: p values resulted from Tukey's multiple comparison test. NS = not significant.
†$p < .001$ (unpaired Student's t test) between men and women in each age group.

was maintained when subjects were grouped by sex and age, except for the oldest women (Table 3). The average decrease in stature was -1.7 ± 3.0 cm and, for the entire series, it was slightly but significantly greater among women than men (-2.2 ± 3.4 cm vs -1.0 ± 2.4 cm, $p < .05$). However, the stature loss was similar in the three age groups, either when the study population was examined as a whole ($F = 0.090$, $p = .914$) or when sexes were analyzed separately (men: $F = 0.224$, $p = .800$; women: $F = 0.100$, $p = .905$). When comparing men and women within each age group, the stature loss tended to be greater among women, but this difference was significant ($p < .01$) only for women in the age range of 75–84 years.

After the observation of an age-related decrease in stature, we calculated a regression model to predict stature from knee height in which age was introduced as a covariate. As in the original Chumlea and Guo (12) method, the introduction of age did not improve the R^2 of the model, nor was our equation more predictive than the Chumlea and Guo method (data not shown).

Discussion

Available data on body height measurements in elderly Caucasian men and women show a high degree of variability, which may be due to different criteria used to select the study population leading, beyond other factors, to differences in age group composition. Differences in the geographical origin of the study population may also partially account for the variability in stature measurements. In general, European anthropometric studies show a greater variability in body height measurements when compared with updated U.S. data (8,14). The Euronut Survey in Europe on Nutrition and the Elderly, a Concerted Action study (15), for example, which examined anthropometric parameters in subject cohorts born between 1913 and 1918 living in 19 cities from 12 European countries, reported that subjects of both sexes from northern Europe are taller than those born in southern Europe. Our data on average stature of older persons living in Dicomano are substantially similar to those recorded in two Italian cities included in the Euronut study. Conversely, a recent study (16) examining the anthropometric data of subjects aged 60 to 97 years from different Italian cities reported a mean stature for both sexes that was slightly lower than that recorded in our study population. These data further stress the obvious importance of geographic factors as determinants of differences in body height and may explain some difficulties commonly encountered in obtaining referential normative data on stature in the general population and, in particular, on statural changes that occur with aging.

As expected, the linear correlation between stature and age and the comparison of the three age groups showed a progressive decrease in body height with increasing age. However, differences in body height were not significant when the oldest and the intermediate age groups were compared, a result that might derive simply by the fewer number of subjects in the oldest age group. Alternatively, this observation, suggesting a progressive attenuation of height loss during the aging process, may be explained by a "secular effect," consisting of a progressive increase of the average stature of the population across subsequent generations (16). We may hypothesize a stronger influence of secular trend on cohorts born after the First World War (65–74 year-old age group). This hypothesis is supported by published analyses of knee height measurements. Some authors demonstrated that age-associated changes in body height are principally due to structural changes in the spine. As a result, the aging process affects mainly the upper body height, whereas the secular trends in skeletal changes can be detected in lower body segments even at an advanced age (6,9,17). In our study, only the youngest group showed a statistically significant difference in mean knee height when compared with the other two groups. Therefore, the wider

Table 2. Comparison Between Measured Stature and Stature Estimated Using Chumlea and Guo (12) Formulas in Subjects Without and With Kyphosis (phase 2, 1995)

	Measured Stature (cm)	Derived Stature (cm)	p Values
Subjects Without Kyphosis			
Men (n = 137)	166 ± 6	166 ± 6	NS
Women (n = 176)	153 ± 6	153 ± 5	NS
All (n = 313)	159 ± 9	159 ± 8	NS
Subjects With Kyphosis			
Men (n = 116)	164 ± 7	166 ± 5	<.001
Women (n = 177)	151 ± 7	152 ± 5	<.001
All (n = 293)	156 ± 9	158 ± 8	<.001

Note: NS = not significant.

Table 3. Comparison Between Statures Measured in 1989 (phase 1) and 1995 (phase 2)

	Group 1 (70–74 years)[†]				Group 2 (75–84 years)[†]				Group 3 (≥85 years)[†]			
	n	1989	1995	*p* Value	*n*	1989	1995	*p* Value	*n*	1989	1995	*p* Value
Stature (cm)												
Men ($n = 114$)	49	166 ± 6	165 ± 6	<.005	50	163 ± 7	162 ± 6	<.05	15	163 ± 5	162 ± 5	<.05
Women ($n = 144$)	59	155 ± 6	153 ± 5	<.001	69	152 ± 7	149 ± 7	<.001	16	149 ± 7	147 ± 6	NS
All ($n = 258$)	108	160 ± 8	158 ± 8	<.001	119	156 ± 9	155 ± 9	<.001	31	156 ± 9	154 ± 9	<.05

Note: NS = not significant.
[†]Age in 1995.

difference in stature between the youngest group and the other two groups might be ascribed to the secular effect.

Because traditional measures of stature are sometimes difficult to be applied to older adults, several estimates of stature derived from measurement of different body segments have been proposed. Many authors have reported that knee height measurement provides the best estimate of stature (3–5,18). Since predictive formulas specifically tested in Italian population samples are not available at present, this study verified the extent of applicability of predictive measurements of stature by the Chumlea and Guo (12) equations in an elderly population. We chose this method for its wide use in the clinical setting and in anthropometric studies, which demonstrated a strong correlation between standing stature and knee height in the recumbent position (2,19). Comparing measured and derived stature, our study confirmed the applicability of the predicting equation in this older, rural population of central Italy. Indeed, when subjects with clinically evident dorsal kyphosis were excluded from analysis, directly measured and derived statures were comparable. This suggests that the Chumlea and Guo (12) method does provide a more accurate estimate of stature in subjects with spine deformities, in whom measured stature may be erroneously less because of the trunk position. In fact, in our series, the difference between measured and derived stature was correlated with the occiput-to-wall distance, which represents an indirect index of dorsal kyphosis. Accordingly, the difference between measured and estimated stature in our series was, although not significantly, slightly less in women than in men, who exhibited a greater occiput-to-wall distance. Moreover, the use of this predictive method may be considered mandatory in subjects unable to stand or in bedridden subjects.

Several studies demonstrated a decrease in stature with aging. Longitudinal studies, such as the present one, provide the most accurate information on the real impact of aging on statural changes, while results from cross-sectional studies may be influenced by the secular effect, consisting of an increase in stature in newly born generations. However, the rate of the age-associated decline in stature differs with study subject selection (7,8,17,20,21). In our study, between 1989 and 1995, Dicomano's elderly population exhibited a statural decrease rate of approximately 1 cm every 6 years for men and 2 cm every 6 years for women, corresponding to an annual decline rate of 0.17 and 0.33 cm per year for men and women, respectively. In spite of this observation, inclusion of age as a correction term did not improve the accuracy of the Chumlea and Guo (12) equation, either in their original work or in our study. Indeed, the R^2 of the regression predicting stature from knee height in our series was not improved when age was introduced in the model. However, overall, our data are comparable to those obtained in the European SENECA study (21) and in the study conducted by Cline and colleagues (7), although Chumlea and colleagues (8) reported a higher decrease rate without significant sex-related differences.

Some relevant limitations of the present study have to be acknowledged. In the cross-sectional analysis, we could analyze the data from only 606 subjects, who represented 70.1% of the entire eligible population. Subjects who did not participate in the study (29.9%) may pose a selection bias to data analysis, since these may include a substantial proportion of persons unable to reach the ambulatory setting because of physical limitations deriving from musculoskeletal disorders and, therefore, with particular difficulties in measurement of stature. However, the mean age and the overall health status, as assessed by information collected from family physicians, were similar for participants and nonparticipants (11). The average difference in stature from 1989 to 1995 for the entire population was -1.7 ± 3.0 cm. The large standard deviation observed, which is substantially greater than the mean value for both the entire population and the two sexes analyzed separately, implies a large variability in differences in body height between 1989 and 1995. Such a large variability originates, in part, by the fact that, over the 6-year interval, 30 of 258 (11.6%) subjects exhibited an increase, which was limited to 1 cm or less in 16 of 30 subjects, rather than a decrease in their stature. Beyond the obvious possibility of errors in measurements that may occur in an epidemiological survey collecting a great quantity of data, we may hypothesize that increases in stature originated from the inclusion of subjects who, during the 1989 study, were suffering from transient musculoskeletal disorders, such as backache. These disorders would imply some degree of dorsal kyphosis and their transient nature might have caused an increase in stature measured at the 1995 follow-up. In contrast, acute events, such as vertebral fractures leading to sudden and abnormally large reductions in body height, and the development of dorsal kyphosis cannot be excluded as further reasons for the large variability in the statural change that was observed longitudinally in our study population. Unfortunately, in 1989, we did not record the presence of dorsal kyphosis, nor did we measure the occiput-to-wall distance or the knee height. Thus, we were unable to detect the origin of the statural changes or to analyze longitudinally the possible age-associated changes in the relationship between standing stature and knee height. Moreover, the measurements were rounded to the nearest centimeter, an approximation that may be inadequate to assess changes in stature over a 6-year interval. This method was chosen essentially because our study was primarily aimed at determining the prevalence of congestive heart failure in the general older population rather than at carrying out extremely accurate anthropometric measurements. A further study limitation was the lack of a test of the reliability of anthropometric measurements that were made, since repetition of measurements by the same physician—although well trained—does not guarantee their precision.

In spite of these limitations, we believe that our study demonstrated that methods to predict stature from measurement of knee height (12) can be correctly and usefully applied to an elderly population of a rural area of central Italy. Indeed, measurement of occiput-to-wall distance and of knee height should be routinely included among the other classic anthropometric measurements, since this might represent a method to analyze the origin of otherwise unexplainable statural increases that may be encountered in a longitudinal perspective. This is particularly true since, as we demonstrated in our study, derived measurements of body height may be more accurate in subjects with a clinically evident kyphosis. Finally, in keeping with previous reports, the present study confirmed, both cross-sectionally and longitudinally, that a significant decrease in stature occurs with aging and that such statural reduction appears slightly more pronounced in women than in men.

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