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**Stature Prediction Equations for Elderly non-Hispanic White, non-Hispanic black, and Mexican-American Persons Developed from NHANES III Data**

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**Abstract**

**Objective** To develop new, nationally representative equations to predict stature for racial/ethnic groups of the elderly population in the United States.

**Design** Anthropometric data for stature, knee height, and sitting height for adults aged 60 years or older were collected from a sample of persons in the third National Health and Nutrition Examination Survey (1988-1994), a national probability sample of the US population.

**Subjects** A gender- and racial/ethnic-stratified sample of 4,750 persons from the US population (1,369 non-Hispanic white men, 1,472 non-Hispanic white women, 474 non-Hispanic black men, 481 non-Hispanic black women, 497 Mexican-American men, 457 Mexican-American women) aged 60 years or older participated in this study.

**Statistical analyses** Sampling weights were used to adjust the individual data to account for unequal probabilities of selection, nonresponse, and coverage errors so that all individual data used in these analyses represented national probability estimates. Regression analysis was performed to predict stature in each gender and ethnic group, and the results were cross-validated.

**Results** Stature prediction models using knee height and age and sitting height and age were evaluated for each gender and racial/ethnic group. The equations with knee height and age were selected on the basis of root mean square error and pure errors in cross-validation and on the accuracy and validity of measures of knee height over sitting height. Results of these regressions, including regression coefficients, standard errors of the coefficients, multiple correlation coefficients, root mean square error, and the standard error for the individual for the final equations, are presented.

**Conclusions** New stature prediction equations using knee height and age are presented for non-Hispanic white, non-Hispanic black and Mexican-American elderly persons from current nationally representative data. These equations should be applied when a measure of stature cannot be obtained, for example, for persons with amputations of the leg, or with spinal curvature or who are confined to bed. Predicted stature values are acceptable surrogates in nutritional indexes. *J Am Diet Assoc. 1998;98:137-142*.

The stature of an elderly person is important because of the role it plays in indexes of nutritional and clinical status and in calculation of nutrient needs. If stature cannot be measured or measured accurately, then a surrogate value must be calculated (1). The method used to calculate or predict a stature surrogate should include body measurements that are actual constituents of stature as predictor variables. The ability to collect these measurements should be independent of a person's level of mobility or health condition. Also, the degree of accuracy of the prediction for a person is needed so that the predicted stature can be evaluated within known confidence limits and adjusted to meet nutrition recommendations. Several methods involve estimating stature from measures of arm span and the lengths of individual bones or body segments [2], [3] and [4]. Of these methods, stature prediction equations that include knee height are increasingly used in nutrition assessments of the elderly worldwide [5], [6] and [7]. The World Health Organization has recommended that when stature cannot be measured, it should be predicted from a measure of knee height for a person aged 60 years or older (1).

Stature prediction equations for the elderly using knee height were first developed from a small sample of non-Hispanic white elderly persons living in southwest Ohio (8). The accuracy of these equations in other samples of elderly non-Hispanic whites was good [9] and [10]. However, this initial sample did not include any non-Hispanic black or Hispanic Americans, and the equations were not developed from nationally representative data (8). Equations developed from nationally representative samples have an increased usefulness among the general population. Nationally representative prediction equations reduce the inherent problem of sample specificity and increase precision and confidence in the predicted stature for a person (11).

The models with knee height and age as predictor variables were the best stature prediction equations for each gender- and racial/ethnic-specific group of older adults

Nationally representative prediction equations for the elderly have been developed previously using data from the National Health Examination Survey (NHES) for non-Hispanic white and black Americans (12). These previous equations were applicable for persons between 60 and 79 years old. These equations were limited, however, in their application to elderly non-Hispanic black Americans because of the small samples available in the NHES data set (12). This NHES data set is now more than 30 years old, and the application of these equations to the majority of the elderly population needs to be reevaluated. Currently, increasing numbers of the elderly are older than 80 years of age and are of African-American or Mexican-American ethnicity. Thus, new stature prediction equations are needed to represent the current elderly population of the United States. Data to develop these equations are available as part of the third National Health and Nutrition Examination Survey (NHANES III) from the National Center for Health Statistics.

## Methods

### Sample

The NHANES III data used in this analysis were collected between 1988 and 1994. The identification of subjects and the collection of data in mobile examination centers in NHANES III was similar to that in previous NHANES studies (13). The initial sampling distribution of households in NHANES III was 40% for non-Hispanic white, 30% for non-Hispanic black, and 30% for Mexican-American subgroups of the US population. However, the number of elderly subjects observed in the mobile examination centers among the 3 ethnic groups was a result of individual response rates. This produced a national probability sample of 4,750 adults (1,369 non-Hispanic white men, 1,472 non-Hispanic white women, 474 non-Hispanic black men, 481 non-Hispanic black women, 497 Mexican-American men, 457 Mexican-American women) aged 60 years or older. A person's racial/ethnic status was based on self-identification, and there was no upper age limit for subject participation.

### Anthropometric Methods

Anthropometric data from NHANES III used in our analyses were for stature, knee height, and sitting height. Descriptions of the measurement techniques used to collect these data have been documented elsewhere (14). The techniques were identical or similar to methods for corresponding measurements listed in the *Anthropometric Standardization Reference Manual*(15) and corresponding measurements taken in NHANES I and II, the Hispanic Health and Nutrition Examination Survey, and NHES [16] and [17].

Briefly, stature was measured on a specially designed stadiometer. A movable tape measure attached to the headpiece was photographed to record the subject's stature. The measure of stature was read from the photograph at a later time. Sitting height was measured on the same stadiometer according to the same protocol, except the subject was seated on a box of known height. Knee height was measured with the subject sitting on a table with legs hanging off the side of the table and knee and ankle joints of the right leg at 90° angles. A sliding caliper (Medical Express, Beaverton, Ore) was placed next to the lower leg in line with the lateral malleolus and the head of the fibula; with the soft tissue compressed, the distance from the sole of the foot to the top of the thigh immediately above the condyles of the right femur was measured. Reliability for these data is at present unknown, but it is expected to be good and to compare favorably with reliability for corresponding measurements in NHANES II and the Hispanic Health and Nutrition Examination Survey [17] and [18].

### Statistical Methods

The subjects within each gender and the 3 racial/ethnic groups were separated into a validation group to develop the gender-and ethnic-specific prediction equations and a cross-validation group to cross-validate the developed equations. Subjects were assigned to the validation or cross-validation group by generating a random number for each subject within each gender and racial/ethnic group and sorting the random numbers assigned in ascending order. The subjects in the first half of the sorted set of random numbers were assigned to the validation group; the remaining subjects were assigned to the corresponding cross-validation group.

Sampling weights were used to adjust individual data to account for unequal probabilities of selection and for nonresponse and coverage errors, so that all data represented national probability estimates (19). Means, standard deviations, and minimum, median, and maximum values were calculated for weighted values of the variables.

Regression analysis was performed using the validation group to predict stature in each gender and ethnic group. Two stature prediction models were developed initially in each gender- and racial/ethnic-specific validation group: one model included knee height and age as predictor variables and the other model included sitting height and age as predictor variables. The regression model with the lowest value of the root mean square error (RMSE) was selected as the best potential model for predicting stature for a group (11).

The accuracy of the models derived from the gender-and ethnic-specific groups was confirmed by applying the equations to the corresponding cross-validation group using the pure error (11). The equations from the validation groups were chosen as the best equations for predicting stature if the pure errors were the smallest among the other corresponding set of equations. A final gender- and ethnic-specific equation to predict stature was then derived after merging the corresponding gender- and ethnic-specific validation and cross-validation groups. This procedure increased the available sample size in each group.

## Results

Descriptive statistics for the variables for each gender- and racial/ethnic-specific group are presented in Table 1. Within each racial/ethnic group, the men had significantly larger ($P$<.05) means for stature, knee height, and sitting height than the women. Between racial/ethnic groups, the non-Hispanic white and non-Hispanic black men had significantly larger mean values for stature than the Mexican-American men. The non-Hispanic white and black men also had significantly larger mean values for knee height than the Mexican-American men, but the mean knee height for the non-Hispanic black men was significantly larger than that of the non-Hispanic white men. The non-Hispanic white men had significantly larger mean values for sitting height than did the non-Hispanic black and Mexican-American men.

Table 1. Descriptive statistics incorporating sampling weights for the data from the third National Health and Nutrition Examination Survey by ethnic group and gender

| **Ethnic group and gender** | **Unit** | **Mean±standard deviation** | **Minimum** | **Median** | **Maximum** |
|---|---|---|---|---|---|
| **Non-Hispanic white men (n=1,369)** | | | | | |
| Age | y | 70.6±7.1 | 60.0 | 73.3 | 102.8 |
| Stature[ab] | cm | 173.5±6.7 | 152.3 | 172.8 | 192.3 |
| Knee height[ab] | cm | 54.2±2.7 | 38.7 | 54.2 | 62.7 |
| Sitting height[ab] | cm | 90.4±3.7 | 72.3 | 90.0 | 101.3 |
| **Non-Hispanic white women (n=1,472)** | | | | | |
| Age | y | 71.8±7.9 | 60.0 | 74.2 | 98.5 |
| Stature[b] | cm | 159.0±6.6 | 126.9 | 158.2 | 178.6 |
| Knee height[b] | cm | 49.5±2.6 | 33.7 | 49.3 | 58.1 |
| Sitting height[b] | cm | 83.0±4.0 | 57.8 | 82.6 | 94.3 |

| | | | | | |
|---|---|---|---|---|---|
| **Non-Hispanic black men (n=474)** | | | | | |
| Age | y | 69.9±7.0 | 60.1 | 69.0 | 96.7 |
| Stature[ab] | cm | 172.7±6.9 | 142.7 | 172.7 | 191.0 |
| Knee height[ab] | cm | 55.5±3.0 | 38.6 | 55.5 | 63.3 |
| Sitting height[ab] | cm | 87.3±3.8 | 75.0 | 87.2 | 97.2 |
| **Non-Hispanic black women (n=481)** | | | | | |
| Age | y | 70.5±7.4 | 60.1 | 68.9 | 91.6 |
| Stature[b] | cm | 160.2±6.2 | 141.3 | 160.3 | 181.3 |
| Knee height[b] | cm | 51.3±2.9 | 40.5 | 51.4 | 59.5 |
| Sitting height[b] | cm | 81.5±3.6 | 70.8 | 81.8 | 93.7 |
| **Mexican-American men (n=497)** | | | | | |
| Age | y | 68.9±7.0 | 60.1 | 67.3 | 96.7 |
| Stature[ab] | cm | 166.9±6.3 | 150.7 | 167.0 | 188.3 |
| Knee height[ab] | cm | 52.2±2.6 | 32.0 | 52.2 | 62.7 |
| Sitting height[ab] | cm | 87.5±3.6 | 76.2 | 87.3 | 97.9 |
| **Mexican-American women (n=457)** | | | | | |
| Age | y | 68.3±7.1 | 60.1 | 66.9 | 96.6 |
| Stature[b] | cm | 153.2±6.3 | 130.5 | 153.0 | 171.3 |
| Knee height[b] | cm | 47.6±2.6 | 36.0 | 47.6 | 54.8 |
| Sitting height[b] | cm | 80.6±4.0 | 63.7 | 80.8 | 91.4 |

[a] Sex difference, $P<.05$.

[b] Ethnic difference, $P<.05$.

Among the women, non-Hispanic black women had significantly larger means for stature and knee height than did the non-Hispanic white and Mexican-American women. The non-Hispanic white women also had significantly larger means for stature, sitting height, and knee height than did the Mexican-American women, and a significantly larger sitting height than that of the non-Hispanic black women.

Descriptive statistics for these corresponding variables were calculated from the random assignments to the gender- and racial/ethnic-specific validation and cross-validation groups. These random assignments were successful in generating corresponding sets of nearly identical groups. The significant gender and racial/ethnic differences in the validation and cross-validations groups were the same as those reported in Table 1.

Regression analyses for the knee height and age and the sitting height and age models in the gender- and racial/ethnic-specific validation groups were conducted (Table 2). For the non-Hispanic white and Mexican-American men and women, the model with sitting height and age as predictor variables had the largest multiple correlation coefficient ($R^2$) values and smallest RMSE values. The parameters for the sitting height and age models of the non-Hispanic white and

Mexican-American men and women were slightly larger than corresponding $R^2$ and RMSE values for the knee height and age models. For the non-Hispanic black men and women, the model with knee height and age as predictor variables has the largest $R^2$ values and the smallest RMSE values.

Table 2. Prediction of stature models in the validation groups

| **Gender and ethnic group** | **Predictor variable** | $R^2$ | **Root mean square error** | **Coefficient of variation** |
|---|---|---|---|---|
| **Men** | | | | |
| Non-Hispanic white | Knee height and age | 0.68 | 3.87 | 2.23 |
| | Sitting height and age | 0.70 | 3.77 | 2.17 |
| Non-Hispanic black | Knee height and age | 0.69 | 3.93 | 2.28 |
| | Sitting height and age | 0.66 | 4.11 | 2.38 |
| Mexican-American | Knee height and age | 0.65 | 3.77 | 2.26 |
| | Sitting height and age | 0.74 | 3.25 | 1.95 |
| **Women** | | | | |
| Non-Hispanic white | Knee height and age | 0.63 | 4.18 | 2.63 |
| | Sitting height and age | 0.73 | 3.61 | 2.27 |
| Non-Hispanic black | Knee height and age | 0.57 | 3.87 | 2.42 |
| | Sitting height and age | 0.56 | 3.92 | 2.45 |
| Mexican-American | Knee height and age | 0.73 | 3.45 | 2.25 |
| | Sitting height and age | 0.73 | 3.45 | 2.25 |

These 2 stature prediction models were then applied to the corresponding gender- and racial/ethnic-specific cross-validation groups. The pure errors for the gender- and racial/ethnic-specific cross-validation groups along with the RMSE values from the validation groups for the knee height and age models are presented in Table 3. The knee height and age models had the smallest pure errors for non-Hispanic white and non-Hispanic black men and women. For non-Hispanic white women and Mexican-American men and women, the pure errors for the knee height and age models were slightly larger than those for the sitting height and age model. These results show that these 2 equations have approximately the same predictive power in the independent cross-validation groups as in the validation groups where the equations were developed.

Table 3. Measures of performance of the selected prediction equations for stature in the cross-validation groups

| **Prediction model** | **Men** | | **Women** | |
|---|---|---|---|---|
| | **PE**[a] | **RMSE**[b] | **PE** | **RMSE** |
| **Knee height and age** | | | | |
| Non-Hispanic whites | 3.62 | 3.87 | 3.80 | 4.18 |
| Non-Hispanic blacks | 3.68 | 3.93 | 3.81 | 3.87 |
| Mexican-Americans | 3.64 | 3.77 | 4.17 | 3.45 |
| **Sitting height and age** | | | | |
| Non-Hispanic whites | 3.89 | 3.77 | 3.65 | 3.61 |
| Non-Hispanic blacks | 4.03 | 4.11 | 3.89 | 3.92 |
| Mexican-Americans | 3.45 | 3.25 | 3.22 | 3.45 |

[a] PE=pure error.

[b] RMSE=root mean square error.

**Final Stature Prediction Equation**

The model with knee height and age was chosen as the best equation for predicting stature for 2 reasons. First, the values of the parameters between these 2 models were similar among the gender- and racial/ethnic-specific groups. Second, the general inability to obtain a valid measure of sitting height in many elderly because of the effects of spinal curvature created a measurement problem difficult to solve. Thus, gender- and racial/ethnic-specific validation and corresponding cross-validation groups were merged and a single equation to predict stature from knee height was developed for each gender- and racial/ethnic-specific group. Results of these regressions, including regression coefficients, standard errors of the coefficients, $R^2$, RMSE, and standard error for the individual for these final knee height equations are presented in Table 4. All regression estimates were significant in each gender- and racial/ethnic-specific group ($P<.05$), and the slopes were positive for knee height and negative for age. The intercepts were roughly equal among the men, but there were large differences in the intercepts among the women. In all of the groups, the slopes for knee height were approximately 1.8 to 1.9, except for the non-Hispanic black women for whom the slope was 1.61. The slopes for age ranged from −0.14 to −0.26. These equation parameters were similar in sign and value to corresponding parameters for stature prediction equations for other gender and racial/ethnic groups developed previously [4] and [12].

Table 4. Recommended equations for predicting stature in non-Hispanic white, non-Hispanic black, and Mexican-American men and women

| **Gender and ethnic group** | **Equation** | $R^2$ | **Root mean square error** | **Standard error for an individual** |
|---|---|---|---|---|
| Non-Hispanic white men | Stature (cm)=78.31+(1.94 knee height) – (0.14 age) | 0.69 | 3.74 | 3.74 |
| Non-Hispanic black men | Stature (cm)=79.69+(1.85 knee height) – (0.14 age) | 0.70 | 3.80 | 3.81 |
| Mexican-American men | Stature (cm)=82.77+(1.83 knee height) – (0.16 age) | 0.66 | 3.68 | 3.69 |
| Non-Hispanic white women | Stature (cm)=82.21+(1.85 knee height) – (0.21 age) | 0.64 | 3.98 | 3.98 |
| Non-Hispanic black women | Stature (cm)=89.58+(1.61 knee height) – (0.17 age) | 0.63 | 3.82 | 3.83 |
| Mexican-American women | Stature (cm)=84.25+(1.82 knee height) – (0.26 age) | 0.65 | 3.77 | 3.78 |

**Discussion**

The intent of this study was to provide updated, nationally representative stature prediction equations for elderly non-Hispanic white, non-Hispanic black, and Mexican-American persons aged 60 years and older. These equations can be used in clinical and field settings where an accurate stature measurement could not otherwise be obtained. These new equations are applicable to greater numbers of elderly persons at much older ages than were the previous sets of equations. To our knowledge, stature predictions are needed most frequently for the oldest elderly.

In developing these new equations, the models with knee height and age as predictor variables were chosen as the best equations in each gender- and racial/ethnic-specific group. Knee height is easy to measure in either a sitting or a recumbent manner in almost all elderly persons, regardless of mobility status. This is not the case for sitting height. A knee height measurement in an elderly person with spinal curvature would be more accurate and valid in comparison with a measure of sitting height. This increased accuracy and validity, and the small difference between the knee height and sitting height models, led to the decision to recommend final equations that included only knee height and age as sets of predictor variables for all gender and ethnic groups. This uniformity of the prediction equations among racial/ethnic groups and between the sexes will reduce possible confusion for clinical users.

Our findings are similar to results we reported previously for stature prediction equations in the elderly [5], [8] and [12]. In the earlier equations, knee height was found to be the best predictor of stature for elderly men, and knee height and age were the selected variables in predicting stature in elderly women. The new equations derived from NHANES III data also contained age, with a negative coefficient, as a predictor for men and women in all 3 racial/ethnic groups. The negative coefficients for age in the earlier equations (for women only) were similar in value to the present coefficients. This inclusion of age in all the present models is probably the result of the NHANES III data set having a larger and older age range than previous data sets. The minimum age was 60 years in all groups, and no upper age restriction was placed on the data set. Thus, the oldest ages ranged up to 96 to 102 years for the non-Hispanic white men and women, the non-Hispanic black men, and the Mexican-American men and women. For the non-Hispanic black women, the oldest age was 91 years. In contrast, the maximum ages of subjects had been set at 75 years in previous NHANES studies and 79 years for NHES. With a sufficient range of ages in the data set, the decrease in stature with age becomes apparent in all gender and racial/ethnic groups. Similar findings are reported for stature prediction equations for French elderly persons (5).

Loss of stature is a factor of aging in non-Hispanic white women, and stature generally decreases with age in both men and women (20). The long bones are believed not to change concurrent with the overall decrease in stature with increasing age. A predicted stature is not reflective of past (lifelong adult stature) because we used current stature (with “shrinkage”) for elderly persons. This decrease in stature with age in the NHANES III data may represent cohort differences and not necessarily true changes, given that the data are cross-sectional. Any cohort differences may also be affected by selective mortality within and between the gender and ethnic groups.

The heterogeneity of conditions afflicting elderly persons increases the errors of prediction. Also, because of the relatively limited sample of non-Hispanic black and Mexican-American elderly persons used to develop the equations, caution should be taken in interpreting or applying these results to other elderly Americans of the same racial/ethnic background. The weighting of these data by the sampling weights to represent a nationally representative sample reduces this problem. Nevertheless, the recommended equations for non-Hispanic black and Mexican-Americans will be somewhat less reliable than the equations for the non-Hispanic white Americans. Also, the majority of the persons in each group were younger than 85 to 90 years. This fact will further reduce the accuracy of predictions for persons at older ages. In addition, the equations were developed using measurements collected from ambulatory elderly persons by means of standard techniques. The use of recumbent anthropometric measurements in these equations should not expand the errors of prediction over those presented because of the small measurement errors for recumbent knee height (8).

Included with the recommended equations (Table 4) are values for RMSE. The RMSE is used when the equation is applied to a group of individuals. Plus or minus twice the RMSE produces the 95% confidence limits for the prediction of stature for each gender and racial/ethnic group value. For an independent group of individuals to which an equation is applied, there is a 95% chance that plus or minus twice the RMSE will cover the true mean stature of that group (21). For an independent group, the closeness of the pure error value to the corresponding RMSE is an indication of the confidence in the predicted statures for the independent group (11).

**Applications**

The clinical importance of the recommended equations in Table 4 appears in the application to a single person. This is the scenario in which these equations are most commonly applied. It is appropriate to use knee height in these prediction equations when stature cannot be obtained or measured accurately. The prediction equations are also more accurate than trying to measure stature in persons who have severe kyphosis or for whom a “good” linear measure cannot be obtained for any reason. For example, a person with a below-the-knee amputation of 1 leg cannot stand for a stature measurement. A knee height measure of the opposite leg can be used to predict stature. Also, for nutritional indexes such as the body mass index, a predicted stature is an acceptable surrogate.

In using these equations, one should consider the person's knee height, age, the value of the predicted stature, and the standard error for the individual. The standard error for the individual (Table 4) provides the distributions of the errors that can be expected in applying these equations to estimate the stature of an elderly man or woman. Plus or minus twice the standard error for the individual provides the 95% confidence limits of the predicted stature for an individual. For example, the 95% confidence range for the predicted stature of a non-Hispanic black woman is plus or minus 7.66 cm from the predicted stature value. Thus, if the predicted stature value for this woman was 165.0 cm, the 95% confidence range would extend from a low of 157.3 cm to a high of 172.6 cm. This range for the standard error for the individual has a 95% chance of including the individual's real stature if it could have been measured. Also, when a person's knee height and age are close to the corresponding means for knee height and age of the group from which the equation was derived, the accuracy of the prediction increases. This means that a Mexican-American man aged 68 years with a knee height measure of 52.5 cm will have a slightly more accurate predicted stature than a similar person aged 75 years who has a knee height of 50.0 cm. All these factors should be considered in any decision to adjust a predicted stature value to fine-tune its clinical use.

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