Predictive equations for stature in the elderly: A study in three Latin American cities

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Abstract

Aim: The aim of this study was to develop predictive equations based on anthropometric data to estimate stature in people 60 years and older in Latin America.
Design: Population-based cross-sectional study in three Latin American cities.
Subjects: Sample sizes were $n = 1657$ (Sao Paulo, Brazil), $n = 1004$ (Santiago, Chile) and $n = 995$ (Mexico City, Mexico).
Method: The prediction equations were fitted by stepwise linear regression analysis. For each country and sex, samples were randomly split into two sub-samples (training and validation sub-samples) using the cross-validation method.
Results: Stepwise regression analysis in the training sample revealed that only knee-height and age had a significant effect on the prediction of height. The values of the shrinkage statistic were below 0.1 indicating the reliability of the prediction equations. The regression equations had standard errors of estimate ranging from 3.3 cm (Chile), 3.6 cm (Brazil) and 4.0 cm (Mexico) for women, and 3.7 cm (Mexico and Chile) and 3.8 cm (Brazil) for men.
Conclusions: Sex-specific stature prediction equations based on knee-height and age were obtained from large representative samples from selected cities of Latin America.

Keywords: *Anthropometry, knee height, stature, prediction, elderly*

Introduction

The population of Latin America is ageing and life expectancy at birth has increased as a consequence of the demographic transition that has occurred over recent decades. The leading causes of death have shifted from infectious to non-communicable diseases and on average people live longer. In parallel, the rising prevalence of chronic diseases, especially

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those related to nutrition, has become a widespread phenomenon in the region (Albala and Vio 1995; Albala et al. 2001). In this context, nutritional evaluation is essential to assess health status in the elderly, since malnutrition and unhealthy lifestyles are among the most important contributors to the morbidity, loss of functionality and mortality of this age group. The key components of the nutritional status assessment of elderly persons are food consumption, body weight, height and body composition.

The nutritional status of elderly persons in Latin America has not been sufficiently documented. The absence of simple easy-to-handle assessment instruments makes it difficult to obtain adequate nutritional data for adults aged over 60 years. One of the simplest ways to evaluate nutritional status is using anthropometric measurements such as weight and height, or a combined index of weight and height, such as the Body Mass Index (BMI = weight/height^2) (Shetty and James 1994; WHO 1997). BMI is a simple and useful method for reflecting body composition with moderately good correlation ($r = 0.6$–0.8) with fat mass and lean mass (Micozzi and Harris 1990). BMI allows the evaluation of the nutritional status, identifying either excess or deficiency in relative weight, while meeting feasibility, validity and low cost criteria. In this context, height may be difficult to register in older subjects, due to their physical limitations and/or skeletal deformities.

Several equations to predict stature based on anthropometric data have been developed for elderly populations in USA, France and Italy, respectively, with a good level of accuracy (Chumlea et al. 1985; Guo et al. 1994; Donini et al. 2000). Nevertheless, the application of these equations in Latin American populations has some limitations due to social and ethnic differences between the Latin American population and the populations for which such equations were developed.

The aim of this study was to develop sex-specific equations, based on anthropometric data, in order to estimate height in people over 60 years from three Latin American countries: Brazil, Chile and Mexico (age range: 60–99 years).

Materials and Methods

Design and subjects

The results of this paper are based on data from a cross-sectional study (SABE study: 'Salud, Bienestar y Envejecimiento' or 'Health, Well-being and Ageing') conducted in three cities of Latin America: Santiago (Chile), Sao Paulo (Brazil) and Mexico City (Mexico). This study was part of a larger project aiming to evaluate health conditions of the elderly in Latin America and the Caribbean supported by the Pan American Health Organization (PAHO) in 1999–2000 (Peláez et al. 2003; Santos et al. 2004; Albala et al. 2005).

Data were collected simultaneously in the three countries using standardised procedures. The samples consisted of persons aged 60 years and older residing in selected cities as follows: (a) Sao Paulo, Brazil: 713 men and 944 women ($n = 1657$), representing 77.3% of the original SABE sample; (b) Santiago, Chile: 389 men and 615 women ($n = 1004$), representing 77.2% of the SABE sample, and (c) D.F., Mexico: 388 men and 607 women ($n = 995$), representing 83.0% of the SABE sample. Men with stature under 151 cm and women under 144 cm were excluded from the analysis of this study.

Anthropometric measurements were carried out by paramedical personnel specially trained for this study. The anthropometric variables initially considered for this study were height, weight, knee-height, mid-arm circumference, calf circumference, waist circumference and triceps skin fold thickness. Height was measured with the subject standing barefoot with heels together, arms at the side, legs straight, shoulders relaxed and head in the Frankfort horizontal plane with heels, buttocks, scapulae and back of the head lying against a vertical wall or a door. These measures were taken in centimeters using a Harpenden Pocket Stadiometer (Holtain Ltd., Crosswell, UK). Weight was assessed using a SECA platform scale graduated to the nearest 0.1 kg with the subject standing on the platform barefoot. Knee height was measured with the subject seated in a chair, using a broad-blade caliper. Measurements were performed on the left leg, positioning the knee and ankle at a 90° angle. The fixed blade of the caliper was placed under the heel and the movable blade was positioned parallel to the fibula over the lateral malleolus and just posterior to the head of the fibula, pressing the two blades to compress the soft tissues. The measurement was recorded to the nearest 0.1 cm. Waist circumference was assessed using a flexible steel tape with the subject standing by wrapping the tape at the level of the umbilicus. Triceps skin fold thickness was measured with a Lange skin fold caliper (Vital Signs, model 68 902, Country Technology, Inc.) at the posterior mid-point between the acromion and the olecranon. Measurements were recorded in mm. Mid-arm circumference was measured midway between the lateral projection of the acromion process of the scapula and the inferior margin of the olecranon process of the ulna. This middle point was marked with the elbow flected 90° and the measurement was made with the arm hanging loosely at the side of the body. The mid-arm circumference was measured with a flexible steel tape and recorded to the nearest 0.1 cm. Calf circumference was registered at the middle of the fleshy and bulky part of the calf with a metallic tape to the nearest 0.1 cm.

Statistical methods

The cross-validation method and stepwise linear regression analyses were used to develop and validate sex-specific prediction equations for predicting height from the variables age, knee height and other anthropometric measurements in each country. For each country and sex, samples were randomly split into two sub-samples of equal size. The first sample (called ‘training sample’) was used to generate prediction equations and the second sample (or ‘validation sample’) was used for validation purposes (cross-validation).

Stepwise selection procedures based on linear regression techniques were used to select the most appropriate set of predictors in the training sample. Subsequently, the regression equations estimated in the training sample were applied to the validation sample in order to obtain estimated values for height. Cross-validity correlation values were calculated as the correlation between such predicted values and the actual height in the validation sample. The difference between the R-squared and the cross-validity correlation is the ‘shrinkage on cross-validation’. According to Kleinbaum et al. (1988), values of shrinkage below 0.1 are indicative of a reliable model and would permit the adoption of prediction equations based on pooled data. Regression diagnostic techniques were applied to check assumptions of linear regression analysis. Standard errors for regression coefficients are reported to allow the computation of confidence and prediction intervals. Student t-test and analysis of variance were used to compare study groups. All statistical analyses were carried out using the STATA 8.2 package (Stata Statistical Software, College Station, TX, USA 2004).

Results

Table I presents sex-specific and country-specific descriptive statistics for age, weight, height, knee-height and BMI. Significant differences by sex and small significant differences by country were observed for all these anthropometric variables (Table I), indicating the appropriateness of estimating separate sex-specific prediction equations for each country. Mean stature based on the equations reported in the literature (Chumlea et al. 1985; Guo et al. 1994; Chumlea et al. 1998) differ significantly from the ones observed in our study.

The correlation coefficient between height and knee height by countries ranged from 0.70 and 0.73 for women and 0.79 and 0.81 for men. A negative association between height and age is observed in all countries.

For each country and sex, the samples were randomly divided into two sub-samples ('training sample' and 'validation sample' respectively). As a consequence of the randomisation procedure, the average for age, knee-height, height, weight and other anthropometric variables were very similar in the training sample as compared to the validation sample. The sex-specific statistics for the anthropometric variables in the training and the validation samples by country are available on request from the first author.

Stepwise regression analysis of the training samples revealed that only knee height and age had a significant effect on the prediction of height and consequently these variables were kept for subsequent prediction equations. Mid-arm circumference, calf circumference, waist circumference and triceps skin fold thickness were not considered to be significant predictors of height. The actual and predicted height were not significantly different in the validation sample.

The shrinkage statistic values were lower than 0.1 for all the considered models. Consequently, sex- and country-specific prediction equations were generated based on pooled data (training sample plus validation sample) (Kleinbaum et al. 1988). The results of cross-validation are presented in Table II. The pure errors of prediction (Guo et al. 1994: 170) were slightly larger than the standard errors of estimate of the validation samples.

Regression coefficients of prediction equations based on the pooled data set and other regression coefficients for the height prediction are shown in Table III. The regression equations had standard errors of estimate ranging from 3.3 cm (Chile), 3.6 cm (Brazil)

Table I. Descriptive statistics for anthropometric measurements by sex and country.

Variables	Brazil Mean ± SD	Chile Mean ± SD	Mexico Mean ± SD	p^*
Women				
Age (years)	72.1 ± 8.14	71.3 ± 8.0	70.0 ± 7.7	<0.0001
Weight (kg)	63 ± 12.4	65.3 ± 12.8	63.2 ± 12.1	0.0311
Height (cm)	152.4 ± 5.2	151.5 ± 4.7	148.3 ± 6.2	<0.0001
BMI (Kg/m^2)	27.1 ± 5.1	28.4 ± 5.2	28.7 ± 5.0	<0.0001
Knee Height (cm)	48.9 ± 2.18	46.9 ± 1.9	47.3 ± 2.4	<0.0001
Men				
Age (years)	73.3 ± 8.16	70.6 ± 7.4	69.5 ± 7.7	<0.0001
Weight (kg)	67.8 ± 12.5	73.3 ± 12.8	70.9 ± 11.3	<0.0001
Height (cm)	165 ± 6.4	164.8 ± 6.6	162.5 ± 6.3	<0.0001
BMI (Kg/m^2)	24.8 ± 4.05	26.9 ± 4.2	26.8 ± 3.8	<0.0001
Knee Height (cm)	52.5 ± 2.66	51.1 ± 2.6	51.7 ± 2.6	<0.0001

*p-values for comparisons across countries are based on analysis of variance tests.

Table II. Cross-validation of the sex-specific prediction equations for stature in validation sample based on knee-height and age as predictors.

Country	Sex	Pure error (cm)	CV (%)
Brazil	Women	3.8	2.5
	Men	4.25	2.6
Chile	Women	4.34	2.9
	Men	5.28	3.2
Mexico	Women	4.9	3.3
	Men	5.28	3.2

CV: coefficient of variation.

Table III. Sex-specific prediction equations for stature based on knee-height and age as predictors.

Country	Sex	Intercept ± SE	Knee-height ± SE	Age ± SE	R^2	SEE
Brazil	Women	69.87 ± 2.77	1.85 ± 0.05	−0.11 ± 0.01	0.58	3.58
	Men	67.2 ± 2.9	1.96 ± 0.05	−0.08 ± 0.02	0.69	3.66
Chile	Women	75.17 ± 3.42	1.78 ± 0.07	−0.10 ± 0.02	0.54	3.24
	Men	64.88 ± 4.13	2.09 ± 0.07	−0.10 ± 0.02	0.7	3.67
Mexico	Women	73.09 ± 3.6	1.87 ± 0.07	−0.19 ± 0.02	0.59	4.00
	Men	63.88 ± 4.1	1.99 ± 0.07	−0.06 ± 0.02	0.67	3.67

SE: standard error.
SEE: standard error of estimate.

and 4.0 cm (Mexico) for women, and 3.7 cm (Mexico and Chile) and 3.8 cm (Brazil) for men. With respect to estimated mean stature, these errors varied by 2.1, 2.3 and 2.7% in women and by 2.2, 2.2 and 2.3% in men, for Chile, Brazil and Mexico, respectively.

To evaluate the possible effect of osteoarticular diseases, a cross-validity method was used by dividing the subjects into two samples according to the self-reported presence of osteoarticular diseases. This analysis revealed no significant effect of osteoarticular diseases in the predictive equations estimation (data not shown).

Discussion

One of the central issues of the ageing process is the change in body composition, characterised by a reduction in total body water, bone and muscular mass, a redistribution of fat mass with a relative increase of total fat mass. Such changes are dependent upon a variety of physiological, psychological and social variables linked to nutritional status in these people (Albala and Olivares 2001; Gerber et al. 2003). Weight loss, obesity, and current protein and body fat contents are all important for the individual's health. The association between body mass and bone mass has been well-documented (Albala et al. 1996). The reduction in skeletal mass produced by ageing increases the risk of skeletal deformations, fractures and functional limitations (Cummings et al. 1995).

Height is one of the anthropometric variables that best reflects skeleton size and has a good association with bone and muscular mass. Actual height may reflect unfavourable nutritional conditions during childhood that cause stunting and a reduction in final stature attained. Although height alone does not help when monitoring nutritional conditions, its measurement is very important for calculating indices of weight in relation to height as BMI. However, skeletal deformities frequently produce a decrease in adult height, while functional limitations may prevent the attainment of accurate anthropometric measurements. In this context, some studies have been performed in order to obtain predictive equations of height in adults older than 60 years as a function of age, sex and anthropometric measurements, such as knee height and arm circumference. Knee height, of which the length remains fixed during adult life, is one of the alternatives that have been used to predict stature. Knee height presented a very high correlation with height in studies in USA (Chumlea et al. 1985; Chumlea and Guo 1992; Chumlea et al. 1998), France (Guo et al. 1994) and Italy (Donini et al. 2000). Chumlea et al. (1985) and Chumlea and Guo (1992) developed equations to predict the stature of adults over 60 years old in USA as a function of knee height, age and sex. Guo et al. (1994) developed equations to predict stature in the elderly population from Toulouse, France, also obtaining a good level of accuracy. Bermúdez et al. (1999) developed equations to correct the height of elderly Hispanic living in Northeastern USA. Donini et al. (2000) developed a unique equation for both sexes to predict stature as a function of age and knee height in an elderly Italian population. Cheng et al. (2001), Knous and Arisawa (2002), Kwok et al. (2002) and Shahar and Pooy (2003) developed stature predictive equations for Asian population, using anthropometric measurements in an elderly population in Taiwan, Japan, China and Malaysia, respectively. Recently, Palloni and Guend (2005) have analysed the pooled data of the six cities with anthropometric measurements from the SABE study. These authors have found that the slope of predictive equations for Blacks, Mulattos, Mestizos and population of Mexican origin were higher than those for Whites. However, it is important to develop country-specific predictive equations given the clear ethnic differences in populations in the Americas (Sans 2000) and the need to have uniform country standards for national health policies purposes.

The required sample size to develop prediction equations depends on the number of independent variables and their relation with the dependent variable (Guo et al. 1994). Osborne (2000) quotes some authors who suggest various sample sizes such as 40 subjects by predictor, 25 subjects by predictor, 50 + eight times the number of predictors and so forth. In this study, the sample sizes are population-based and large enough to estimate accurately the height in older adults. On the other hand, the verification of all assumptions of the regression analysis is indispensable in order to obtain regression equations for predictive purposes. In this context, we have used regression diagnostic techniques to check key assumptions of the linear regression analysis such as the linearity between the height and all the independent variables analysed, the normality of errors, the specifications for the models, the homogeneity of variance, the error independence and the absence of collinearity or influential observations.

The equations reported herein were obtained from large representative samples from the selected cities, thereby allowing for the possibility of their application to other groups of people in these countries. Therefore, it represents a useful contribution to the assessment of nutritional status in Latin American elders.

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Résumé. *But:* Cette étude a pour but de développer des équations prédictives à partir de données anthropométriques, afin d'estimer la stature des personnes âgées de 60 ans et plus en Amérique latine.
Sujets et méthodes: Etude transversale d'échantillons de populations dans trois villes d'Amérique latine: $n = 1657$ (Sao Paulo, Brésil), $n = 1004$ (Santiago, Chili) et $n = 995$ (Mexico City, Mexique). Les équations de prédiction ont été ajustées au moyen d'analyse de régression linéaire pas à pas. Dans chaque nation et pour chaque sexe, les échantillons ont été divisés en deux sous échantillons (de de formation et de validation) au moyen d'une méthode de validation croisée.
Résultats: L'analyse de régression pas à pas de l'échantillon de formation révèle que seuls la hauteur du genou et l'âge, ont un effet significatif sur la prédiction de la stature. Les valeurs des statistiques de tassement sont inférieures à 0,1, ce qui indique la fiabilité des équations de prédiction. Les équations de régression ont un écart-type variant de 3,3 cm (Chili), 3,6 cm (Brésil) et 4,0 cm (Mexique) pour les femmes et 3,7 cm (Mexique et Chili) et 3,8 cm (Brésil) pour les hommes.
Conclusions: Des équations de prédiction de la stature par sexe, fondées sur la hauteur du genou et l'âge, ont été élaborées à partir de vastes échantillons représentatifs d'une sélection de villes d'Amérique latine.

Zusammenfassung. *Ziel:* Das Ziel dieser Studie war die Entwicklung von Vorhersagegleichungen, um in Lateinamerika auf der Grundlage von anthropometrischen Daten die Körperhöhe bei Personen von 60 Jahren und älter zu schätzen.
Studienaufbau: Eine bevölkerungsbasierte Querschnittsstudie aus 3 Lateinamerikanischen Städten.
Probanden: Die Studienumfänge betrugen $n = 1657$ (Sao Paulo, Brasilien), $n = 1004$ (Santiago, Chile) und $n = 995$ (Mexico City, Mexiko).
Methode: Die Vorhersagegleichungen wurden durch schrittweise lineare Regressionsanalyse angepasst. Getrennt nach Land und Geschlecht wurden die Stichproben nach Zufallskriterien unter Verwendung der Kreuzvalidierungsmethode in je 2 Untergruppen geteilt (Trainings- und Validierungsgruppe).
Ergebnisse: Die schrittweise Regressionsanalyse zeigte in der Trainingsstichprobe, dass nur Kniehöhe und Alter einen signifikanten Einfluss auf die Vorhersage der Körperhöhe hatten. Die Werte der shrinkage Statistik (Statistik auf der Basis reduzierter N-Zahl) waren unter 0,1 und zeigten damit die Reliabilität der Vorhersagegleichungen. Die Regressionsgleichungen hatten einen Standardschätzfehler von 3,3 cm (Chile), 3,6 cm (Brasilien) und 4,0 cm (Mexiko) für Frauen und von 3,7 cm (Mexiko und Chile) und 3,8 cm (Brasilien) für Männer.
Zusammenfassung: Auf der Grundlage von Kniehöhe und Alter wurden anhand von großen repräsentativen Stichproben aus ausgewählten Lateinamerikanischen Städten geschlechtsspezifische Vorhersagegleichungen für Körperhöhe entwickelt.

Resumen. *Objetivo:* El objetivo de este estudio fue desarrollar ecuaciones de predicción basadas en datos antropométrico para estimar la estatura en personas de 60 años o más, en Latinoamérica.
Diseño: Estudio transversal basado en poblaciones de tres ciudades latinoamericanas.
Sujetos: los tamaños muestrales fueron $n = 1.657$ (Sao Paulo, Brasil), $n = 1.004$ (Santiago, Chile) y $n = 995$ (Ciudad de México, México).

Método: Las ecuaciones de predicción se ajustaron mediante un análisis de regresión lineal ‘‘paso a paso’’. Para cada país y sexo, las muestras fueron divididas aleatoriamente en dos submuestras (submuestras de entrenamiento y de validación), utilizando el método de validación cruzada.
Resultados: En la muestra de entrenamiento el análisis de regresión ‘‘paso a paso’’ reveló que sólo la altura de la rodilla y la edad tenían un efecto significativo sobre la predicción de la estatura. Los valores de contracción (‘‘shrinkage’’) estadística estaban por debajo del 0,1, lo que indicaba la confiabilidad de las ecuaciones de predicción. Los errores estándar de la estima de las ecuaciones de regresión oscilaban entre 3,3 cm (Chile), 3,6 cm (Brasil) y 4,0 cm (México), en las mujeres, y entre 3,7 cm (México y Chile) y 3,8 cm (Brasil), en los varones.
Conclusiones: Se obtuvieron las ecuaciones de predicción de la estatura, específicas para cada sexo, basadas en la altura de la rodilla y la edad, en grandes muestras representativas de las ciudades latinoamericanas seleccionadas.