



Applied nutritional investigation

Development of regression equations for estimating height and weight using body segments in Argentine children

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ABSTRACT

Objectives: Body weight and height measurements are essential in children for assessing growth and nutrition, for the calculation of medication doses, and for the effectiveness of medical interventions. When direct measurements cannot be made, segmental measures can be used to estimate weight and height. The equations available to estimate height and weight, however, are limited. The aim of this study was to use segmental measures to develop equations for use in pediatric clinical practice.

Methods: A cross-sectional study design was used to collect data from 861 healthy children (484 females and 377 males) ages 2 to 18 y to develop equations for estimating weight and height from midarm circumference (MAC) and knee–heel height (KH), respectively. A multi-linear regression model was used to develop the equations.

Results: The high correlation between MAC and the actual weight and KH and height indicates strong agreement. Four equations were developed to estimate weight and height using segmental measures.

1. To estimate weight from MAC for females: $W = 2.37 \times \text{MAC} + 1.64 \times \text{age (y)} - 28.28$.

2. To estimate weight for males: $W = 2.54 \times \text{MAC} + 1.82 \times \text{age (y)} - 32.73$.

3. To estimate height from KH for females: $H = 2.88 \times \text{KH} + 0.15$.

4. To estimate height from KH for males: $H = 2.73 \times \text{KH} + 0.21$.

Conclusions: MAC and KH can be used for estimation equations for weight and height with a very good predictive power. Sex and age were significant covariates in estimating weight. To predict height, only sex was needed to fit the model.

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Introduction

Growth is an essential aspect of health and an indicator of well-being in children. Abnormal growth may indicate inadequate nutrition, illness, and failure to thrive or survive. Research in pediatric groups has documented negative effects of poor nutrition in many organ systems (i.e., respiratory [1]; cardiac [2,3]; immune

[4,5]; and impaired motor, cognitive, and social behavior and development [6–11]. Nutritional assessment is a useful tool for monitoring growth and nutrition [12,13], for the calculation of medication doses or glomerular filtration [14], especially in hospitalized children, and for evaluating the effectiveness of medical interventions. Among nutritional assessment methods, direct measurements of body weight and height are the most widely used. However, this is difficult or impossible in children who are critically ill, immobilized, or in those who have bone deformities or neuromuscular disease. Although there is special equipment such as scales integrated into hospital beds, this equipment is expensive and not readily available in many hospitals in middle- and low-income countries.

Therefore, various research groups have developed equations to estimate body height and weight from specific measures of body segments. Height equations have been published by research groups based on normative samples of healthy children around the world using segmental measures [15–19]. It had been

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demonstrated that long bones behaved or correlated similarly to knee–heel (KH) height, but found KH easier to measure reliably.

On the other hand, there are many settings where scales are unavailable, and weight cannot be recorded [20–22]. Research groups have published weight equations from samples of healthy children in different countries using segmental measures [15,17,23,24]. Most of them used midarm circumference (MAC) exclusively. One used MAC and calf-plus-wrist circumference, combining these three in their equation. Most recently, Children's Mercy Hospital in the United States developed the Mercy method [25], which uses a measuring tape they designed with anthropometric surrogates for both height (humeral length) and body build or physique (midupper arm circumference). It was found to give a more accurate estimate of weight than methods that rely on a single variable that is not also a segmental measure of the children (e.g., age).

However, each one of them has limitations for generalized use because of the following:

- The equations are based on normative data from sample populations that vary widely (e.g., by ethnicity, physical capacity, or age).
- Some require multiple or complex formulas that are not practical in clinical use.
- Some of the segmental measures used are too difficult to be reliably measured without specific training.
- Most methods are based on growth standards for children in developed countries.
- All of them are restricted for general use by the age range of the individuals for whom they were designed.

The purpose of this study was to develop a valid and reliable method for estimating height and weight using a normative sample of non-disabled, healthy Argentine children, 2 to 18 y of age. The goal was for these equations to cover a larger age group range than those previously published and to be simple enough for daily clinical use. They will be used for children who are hospitalized and cannot be measured for height and weight directly and in clinics that do not have the equipment needed. Our intention is to first develop equations for children without disabilities to establish which segmental measures to use and which variables affect the equations from this relatively large sample. The next step in future research will be to modify these equations for use in children with cerebral palsy.

Methods

Research design, participants, and setting

A cross-sectional study design was used to collect prospective data from healthy, non-disabled children, 2 to 18 y of age. Children with amputated limb(s), inability to move, and chronic disease that could affect or have affected their

growth were excluded. With parental consent, measurements were made in a public and a private ambulatory clinic, and one public school in the metropolitan area of Córdoba between July 2014 and July 2016. The sample was taken successively and subsequently, divided into 16 strata from 2 to 18 y of age, for each sex. There were 861 participants. From the 1025 assessed for eligibility based on healthy child checkup appointments from both hospital and the school registers, 164 children were excluded for not meeting the inclusion criteria, declined to participate, were absent on the days of data collection. From the 861 children, 484 were females (56.2%; 95% confidence interval [CI], 52.8–59.5) and 377 were males (43.8%; 95% CI, 40.4–47.2). The range of decimal ages for the females was from 2.375 to 18.923 y, and for the males, 2.013 to 18.948 y.

The institutional ethics committee of a private hospital in Córdoba (Argentina) approved this study.

Measures and procedures

Reliability

Four research assistants were trained in the measurement method for each of the four anthropometric parameters. Inter- and intrarater reliability testing was performed before data collection with kappa agreement with acceptance level set at >80% with ≤5% error.

Overall weight and height

Normative weight and height were assessed in the usual way with participants independently standing: on the same standard scale with weight recorded in kilograms to one decimal, and against the same standard height measurement board with head, shoulder blades, buttocks, and heels touching the board, recorded in millimeters.

Measures of body segments for estimation of weight and height

Based on the experience and findings of previous research groups, we chose MAC to calculate and estimate normative overall weight. A regular flexible and inelastic measuring tape (in centimeters and millimeters) was used to make the measurements on the right side of the body. MAC was measured at the midpoint between the acromion and the olecranon. The child was standing up with his or her arm bent 90° at the elbow, and the right palm facing up.

For the same reason, we chose KH height to calculate and estimate overall height. The child was seated upright with feet flat on the floor with both the knee and ankle joints flexed at angle of 90°. The measurement was taken as the distance from the floor, or foot rest, to the anterior surface of the thigh just proximal to the patella. The shaft of the caliper was held parallel to the tibia and gentle pressure applied to the blades of the caliper to blanch the skin and compress the tissue.

All measurements were performed with the participant wearing light clothing with shoes and socks removed. Demographic data of sex and decimal age were also collected.

Statistical analysis, parameter selection, modeling, and validation

STATA 13.0 (Stata Corp LP, College Station, TX, USA) was used for analysis. Continuous data were tested for normal distribution with Kolmogorov-Smirnov test and reported as mean ± SD. To develop equations that are simple enough for use in clinical practice, a linear regression model was used to identify the relationship between the independent variables (MAC, KH height) and the dependent variables (weight, height). The acceptable statistical difference was predefined as $P < 0.05$.

Bland-Altman plots [18], with 95% limits of agreement, were created from the data to observe and analyze the agreement between the measured heights and weight, and their estimated values.

Table 1
Characteristics of participants

	Sex													
	Females							Males						
	N	Mean	95% CI	SD	Min	Max	Normal distribution	N	Mean	95% CI	SD	Min	Max	Normal distribution
Decimal age	484	10.59	10.22–10.95	4.1	2.4	18.9	<0.0001	377	10.170	9.73–10.61	4.4	2	18.9	<0.0001
Weight (kg)	484	38.00	36.63–39.37	15.4	11.8	89.8	0.0001	377	38.70	36.76–40.65	19.2	10	97.4	<0.0001
Height (m)	484	1.38	1.36–1.40	0.2	0.8	1.7	<0.0001	377	1.38	1.36–1.41	0.2	0.8	1.9	<0.0001
Knee height (m)	484	0.43	0.42–0.43	0.1	0.2	0.6	<0.0001	377	0.43	0.42–0.44	0.09	0.2	0.6	<0.0001
MAC (cm)	484	20.97	20.63–21.31	3.8	12.5	35	0.0004	377	21.2	20.74–21.67	4.6	12.5	35.7	<0.0001

MAC, midarm circumference

Table 2
Inter- and intrarater reliability testing

	Weighted kappa	Standard error	95% CI	Agreement
Interrater	0.868	0.029	0.811–0.925	Almost perfect agreement
Intrarater	0.952	0.007	0.938–0.966	Almost perfect agreement

Results

The characteristics of the 861 participants based on ages, weight, height, MAC, and KH are shown in Table 1.

Before the data collection inter- and intra-rater reliability testing was performed with kappa agreement obtaining the data presented in Table 2.

The correlation coefficient r between weight and MAC was 0.87 for the females and 0.92 for the males, both with $P < 0.001$. The correlation coefficient between height and knee height was 0.98 for females, and 0.98 for males, both with $P < 0.001$. This high correlation between the body segments and the actual weight and height indicates strong agreement.

To develop the predictive equations, an analysis of the body segments, MAC, and KH, combined with different covariates, was performed in a multi-linear regression model where R^2 , adjusted R^2 , and root-mean-square error were analyzed. The results of this analysis are shown in Tables 3 and 4.

Gender and age proved to be significant covariates that improved the model to estimate weight, fitting the R^2 better and lowering the root mean square of the error. However, to predict

Table 3
Goodness-of-fit analysis: Linear regression between weight and MAC

Parameter	R^2	Adjusted R^2	RMSE	P -value
MAC	0.81	0.81	7.53	<0.0001
MAC by sex				
Female	0.76	0.76	7.52	<0.0001
Male	0.85	0.85	7.48	<0.0001
MAC + age (y) by sex				
Female	0.87	0.87	5.48	<0.0001
Male	0.92	0.92	5.403	<0.0001

MAC, midarm circumference; RMSE, root-mean-square of error

Table 4
Goodness-of-fit analysis: Linear regression between height and KH

Parameter	R^2	Adjusted R^2	RMSE	P -value
KH	0.97	0.97	0.041	<0.0001
KH by sex				
Female	0.96	0.96	0.034	<0.0001
Male	0.97	0.97	0.042	<0.0001

KH, knee-heel; RMSE, root-mean-square of error

Table 5
Predictive equations for weight and height

Equations to estimate weight	Equation
Parameter	
MAC + age (y) by sex	
Females	$W = 2.37 \times \text{MAC} + 1.64 \times \text{age (y)} - 28.28$
Males	$W = 2.54 \times \text{MAC} + 1.82 \times \text{age (y)} - 32.73$
Equations to estimate height	
Parameter	
KH by sex	
Females	$H = 2.88 \times \text{KH} + 0.15$
Males	$H = 2.73 \times \text{KH} + 0.21$

H, height; KH, knee-heel; MAC, midarm circumference; W, weight

height with KH, only gender was needed to fit the model. From this analysis the equations were developed for each gender Table 5.

The Bland–Altman plots showed a strong consistency between the observed and the predicted values for weight and height. Between the weight observed and the estimated weight (Fig. 1) the limits of agreement (reference range for difference) was -10.858 to 10.858 . The mean difference was -0.000 (95% CI, -0.363 to 0.363). For the height observed and the estimated values (Fig. 2) the limits of agreement (reference range for difference) was -0.081 to 0.080 . The mean difference was -0.000 (95% CI -0.003 to 0.002).

Discussion

This study showed that KH height and MAC can be used to estimate height and weight in children. KH height presented a very high correlation with height. The results were similar to those of other investigations, where measuring the tibia trough, KH height, or tibia length was a better estimator for predicting height between the long bones [26] reflecting linear child growth [27]. In clinical practice, as other investigations showed [19,28], KH height turned out to be the best option as the landmarks are easier to palpate, which minimizes the risk for technical errors. We have demonstrated the prediction equations based on KH height can be used to estimate height in children when it is not possible to take accurate measurements in children who are critically ill, immobilized, or in those with bone deformities.

Also, this study showed that MAC has a high correlation with weight. Other authors also found evidence that the MAC can be used for this purpose. The technique can be taught quickly to clinical staff, requires a low-cost tool, does not require patients to move, and has proved to be the best screening tool to evaluate malnutrition as an indicator of body fat and muscle level [29–33]. Additionally, MAC can be used in children as an indicator of general health [34]. It is useful to be able to measure segmental body parts as a daily routine in clinical practice to monitor nutrition and growth. Additionally, growth charts of segmental measures can facilitate growth assessment in children with and without disabilities.

The predictive equations for height and weight have been developed with a multi-linear regression model using only one body segment to estimate height, and only MAC and age to estimate weight. These equations can be used with children between the ages of 2 and 18 y, extending the age group previously used in others' equations.

The equations to predict height have not showed a better predictive capacity when combined with age or other segmental measures. Only sex added a significant predictive capacity to the equation. Stevenson [19] and Cattermole et al. [23] did not report differences in the correlations between segmental measures and stature resulting from age, race, or sex. Although we found no difference in the correlations with age and sex, we did verify that including sex adds a significant predictive capacity. This may result in part, for the different growth patterns between males and females.

To estimate weight, some authors have reported predictive equations with non-segmental factors (e.g., age) as well as other segmental body measures [18]. However, these authors do not report whether this adds a better predictive capacity to the equations. Cattermole et al., in their study of a Chinese population of

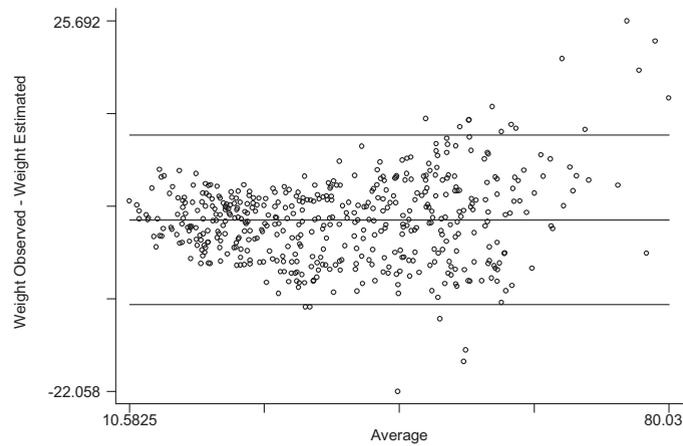


Fig. 1. Bland-Altman plot for the agreement between estimated weight and observed weight. Data points represent the individual children. The mean is represented by the centered line, and the upper and lower lines represent the SD and the 95% CIs for the agreement between the two methods.

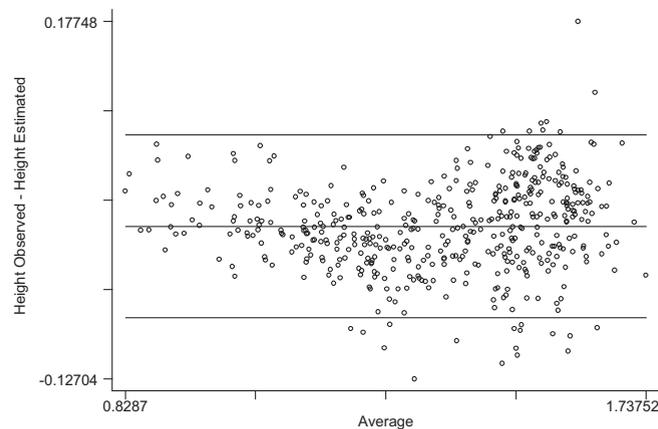


Fig. 2. Bland-Altman plot for the agreement between estimated height and observed height. Data points represent the individual children. The mean is represented by the centered line, and the other two lines represent the SD and the 95% CIs for the agreement between the two methods.

children, observed that MAC has a strong correlation with children's weight, and that this relationship strengthens with age [23]. We also found that only age and sex add a significant predictive capacity to the equations to estimate weight. The Mercy method [25], instead of using age, adds another segmental measure such as humeral length, obtaining similar results. One difference between the present study and the Mercy method is that the result of the present study is an equation, and the Marcy method is a reading from a measuring tape that indicates the estimated weight based on an unpublished mathematical calculation. However, neither this measuring tool, nor the calculation, is currently available to the field.

There are some potential limitations to this study. The equation is based on an Argentine population, and caution should be exercised when applying these equations to another ethnic groups. In addition, these equations are derived for healthy children without any chronic disease that could affect or has affected their growth; they are not appropriate for use in children with disabilities such as cerebral palsy. Further studies will be needed in disabled populations.

On the other hand, this study has several strengths. It is one of the largest prospective studies published to propose equations, so we were able to perform inter- and intrarater reliability testing. Most studies with larger samples use data sets. Furthermore, this has been the largest study based on a population in Argentina to use segmental measures to estimate weight and height creating a segmental measures-based

formula, and to cover a larger age group range than those previously published.

Conclusions

The equations developed in the present study using KH height and MAC are accurate to estimate height and weight in children from 2 to 18 y of age in an Argentine sample. These equations are easier to use in different clinical settings using instruments that are simple, low-cost, and widely distributed and using body segments that are easy to measure so the risk for error in collecting the data is lower [27,35]. Based on these findings, we are developing specific equations for children with cerebral palsy.

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