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Height Prediction From Ulna Length of Critically Ill Patients

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Abstract

Background: Ulna length (UL) has been used in mathematical formulas to predict the body height of healthy and sick individuals. However, the evaluation of its use with patients admitted to intensive care units (ICU) is scarce. The objective of this study was to develop a mathematical equation to estimate critically ill patients' height using the UL measure and to evaluate its agreement with measured standing height. *Methods:* This cross-sectional study was performed at the ICU of a tertiary hospital in Brazil. A total of 100 patients aged ≥18 years who had their body height measured before ICU admission were enrolled. The equation was developed through multiple linear regression, and its agreement was assessed through paired Student's *t* test and Bland-Altman plot. *Results:* The following formula was obtained: height in cm = 153.492 – (7.97 × sex [sex: male = 1, female = 2]) + (0.974 × UL [in cm]). The difference between means of measured height (MH) and height estimated from UL was not significant (166.26 ± 8.75 cm and 166.30 ± 5.29 cm, respectively, $P = .96$), and a significant correlation ($r = 0.624$, $P < .001$) was detected. In the Bland-Altman analysis, UL was in agreement with MH; however, there was a significant bias ($P < .001$) suggesting that it may be disproportional and dependent on the average's height value. *Conclusion:* The mathematical equation for height estimation using UL developed in this study matched the MH of critically ill patients. However, we suggest more studies for its validation. (*Nutr Clin Pract*. XXXX;xx:xx-xx)

Keywords

nutritional assessment; ulna; body height; intensive care units; critical illness

Nutrition assessment is crucial to develop therapeutic plans and evaluate their effectiveness, particularly for critically ill patients.[1] Anthropometric evaluation is generally impaired for critical patients because of the high complexity of their clinical state, with limitations and difficulties related to immobilization, the equipments required, and the significant edema often present in this population.[2]

The Sociedad Española de Nutrición Parenteral y Enteral (Spanish Society for Parenteral and Enteral Nutrition) recommends that body mass and height be assessed when patients are admitted to intensive care units (ICUs).[3] Such assessment can be used for nutrition and medical management procedures, such as drug dose prescription, parameters for mechanical ventilation, energy needs estimate, and ideal body weight calculation.[3-5]

The absence of exact anthropometric information is a reality in ICUs, where there is no gold standard for nutrition assessment in critically ill patients. In this context, the definition of energy and protein prescription goals must be based on plausible estimates of body mass and height, to avoid malnutrition, overfeeding, and incorrect nutrition diagnosis.[4] Therefore, measurements of different body compartments, such as the length of long bones (considered good predictors of body height), are feasible alternatives.[6] Ulna length (UL) has been used because it is a reliable height predictor, easily obtained in bedridden patients, and less affected by the aging process when the standing body height measure is difficult to obtain.[7]

Studies suggest the use of mathematical equations for determining body height through UL.[6,8-14] The Malnutrition Universal Screening Tool (MUST) also suggests the use of UL to estimate standing height for body mass index (BMI) calculation to determine the nutrition risk classification.[15]

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However, such methods and equations were developed and validated with distinct population groups, based on sex, age, and race, but not critically ill patients. The use of UL to predict the height of critically ill patients would be useful, being a quick and easily applicable method. Besides, alternative measurements to estimate body height, such as knee height (KH), may have some limitations in the ICU, particularly with patients who are overweight, have bilateral amputations, or have femoral venous access.[6]

The use of UL to predict standing height was shown in a Brazilian population admitted to an emergency room.[16] However, in this study, the method suggested by MUST was used to identify the values of estimated height according to UL. Therefore, the main objective of our study was to develop a mathematical formula to estimate the standing body height of critically ill patients with their UL and to evaluate its agreement with the measured height (MH). As a secondary objective, we evaluated the agreement between the estimated height according to a mathematical formula that uses the KH measurement and the MH of the subjects.

Methods

This cross-sectional study was carried out between September 2015 and August 2016. Patients admitted to a general ICU were enrolled (Santa Clara Hospital, Brotherhood of the Santa Casa of Porto Alegre, Porto Alegre, Brazil). The study included individuals of both sexes, aged ≥18 years, whose standing body height was previously measured at inpatient hospital units and recorded in their medical records before being admitted to the ICU. They agreed to be part of the research and signed the informed consent form (or their legal representatives). Individuals with incomplete medical records, those without MH previously registered, and those whose KH could not be obtained at the ICU were excluded.

The data were recorded in a standardized questionnaire. Age (years), sex, ICU length of stay (days), and reason for admission in the ICU (cardiovascular, gastrointestinal, respiratory, postsurgery, infection/sepsis, shock, and other) were the information collected from the electronic medical records to characterize the sample.

The nutrition risk and/or nutrition status classification was obtained through the Nutrition Risk in the Critically Ill (NUTRIC) score,[17] Subjective Global Assessment,[18] and BMI (kg/m^2), calculated with the patient's body mass and MH. The patient's body mass (kg) was obtained directly through the electronic medical record (if the patient was weighed up to 48 hours before ICU admission) or estimated through a mathematical formula[19] (in the first 48 hours after of ICU admission).

Height was measured by the hospital nursing and nutrition staff, with stadiometers assembled with weighing scales available in inpatient hospital units. The professionals were trained to follow the same protocol: place the patient in a standing position, barefooted, wearing the least amount of clothing possible, with arms positioned alongside the body and hands turned toward the thighs. MH was recorded in centimeters.

The other anthropometric indexes were measured in the first 48 hours after ICU admission by 2 trained nutritionists:

UL (cm): Measured with a bone anthropometer caliper (WCS: Cardiomed, Curitiba, Brazil; range up to 280 cm; 1-mm resolution) positioned between the elbow's tip (olecranon process) and the midpoint of the wrist prominent bone (styloid process), according to MUST protocol.[15] UL was measured preferentially in the left arm of the patient, folded in front of the patient's chest, with fingers pointing to the opposite shoulder.

KH (cm): Measured with a bone anthropometer caliper (WCS) with individuals in the supine position and the right leg forming a 90° angle with knee and ankle. Estimated body height according to KH (KHH) was calculated according to mathematical formulas proposed by Chumlea et al[20]: for men, 64.19 – (0.04 × age in years) + (2.02 × KH in cm); for women, 84.88 – (0.24 × age in years) + (1.83 × KH in cm).

Statistical Analysis

The analyses were performed with SPSS 22.0 (IBM, Chicago, IL). Continuous variables were described with mean and standard deviation (variables with normal distribution) or median and interquintile interval (nonparametric variables); absolute numbers and frequencies were used to describe qualitative variables. Multiple linear regression, in stepwise method, was used to create the body height–predictive mathematical formula based on UL. Pearson's correlation test was used for correlations of the different heights (MH, UL height [ULH], and KHH). Agreements among the heights were evaluated through Student's *t* test for paired samples, multiple linear regression for assessing the bias significance, and Bland-Altman plot. $P < .05$ values were considered significant.

The study was approved by the Research Ethics Committee of the Brotherhood of the Santa Casa of Porto Alegre (protocol 40073414.9.0000.5335) and by the Research Ethics Committee of the Federal University of Health Sciences of Porto Alegre.

Results

In total, 100 patients who stayed a median of 8 days (range 3–15) in the ICU were evaluated. Regarding the leading causes to ICU admission, 35% of the patients had postsurgery complications; 21% were in shock; and 12% had gastrointestinal or respiratory diseases. According to the Subjective Global Assessment, 28% of the patients were moderately undernourished, and 20% were severely undernourished; 7% had a BMI <18.5 kg/m^2. Demographic and anthropometric data related to the sample are described in Table 1.

Table 1. Characteristics of the Sample.[a]

Variables	Total Sample (N = 100)
Sex	
Male	57 (57)
Female	43 (43)
Age, y	62.47 ± 16.60
Body mass index, kg/m^2	24.49 ± 4.93
NUTRIC score	
High nutrition risk	22 (22)
Low nutrition risk	88 (88)

NUTRIC, Nutrition Risk in the Critically Ill.
[a]Values are presented as n (%) or mean ± SD.

Table 2. Linear Regression Model Used to Identify the Predictive Equation for Height.[a]

	Nonstandardized Coefficient			
Factors	B	SE	*t*	*P* Value
Constant	153.492	9.467	16.214	<.001
Sex	−7.970	1.632	−4.884	<.001
Ulna length, cm	0.974	0.322	3.030	.003

[a]Dependent variable: standing measured height (cm). $R^2 = 0.364$.

Two models were used for the construction of the predictive mathematical formula: in the first, the linear regression model included age, sex, and UL; in the second, sex and UL only. The analysis showed that among all variables used, sex and UL were the best predictors of MH, the residues of which showed normal distribution and were independent of one another (Durbin-Watson test = 1.742). Therefore, the following mathematical formula for height prediction was obtained: height in cm = 153.492 − (7.97 × sex [sex: male = 1, female = 2]) + (0.974 × UL [in cm]). Statistical data related to the equation of ULH are presented in Table 2.

Figures 1 and 2 show scatter plots and the correlations between MH and ULH (Figure 1) and between MH and KHH (Figure 2). Both were statistically significant ($P < .001$); however, MH and ULH presented a superior correlation ($r = 0.624$) versus MH and KHH ($r = 0.592$).

Regarding means of different measures of height, MH was 166.26 ± 8.75 cm; ULH, 166.30 ± 5.29 cm; and KHH, 157.56 ± 8.73 cm. There was no significant difference between the averages of MH and ULH (difference = −0.04 cm, $P = .96$), suggesting an agreement between the methods. The Bland-Altman plot (Figure 3) shows the limits of agreement (mean differences ± 2 standard deviations) as well as the bias. The result of this was significant in the linear regression analysis ($P < .001$), suggesting that the limits of agreement depend on the average height values and that the bias may be disproportional: when mean height values are small, the difference between methods is small; when mean height values increase, so does the difference between methods.

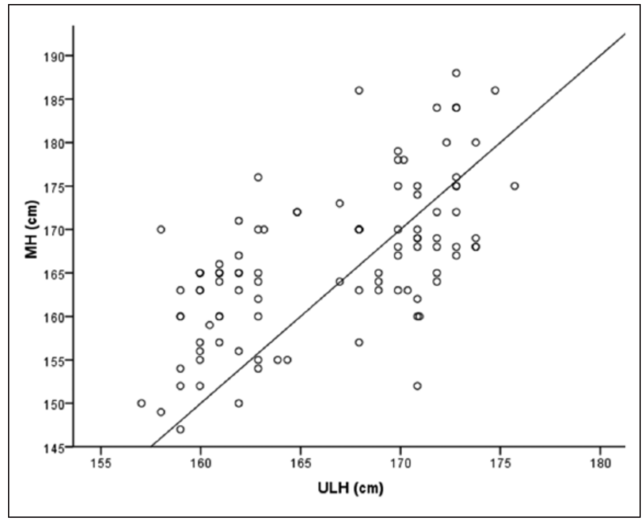

Figure 1. Scatter plot showing the correlation between measured height (MH) and height estimated from ulna length (ULH; equation proposed by authors). $r = 0.624$ ($P < .001$).

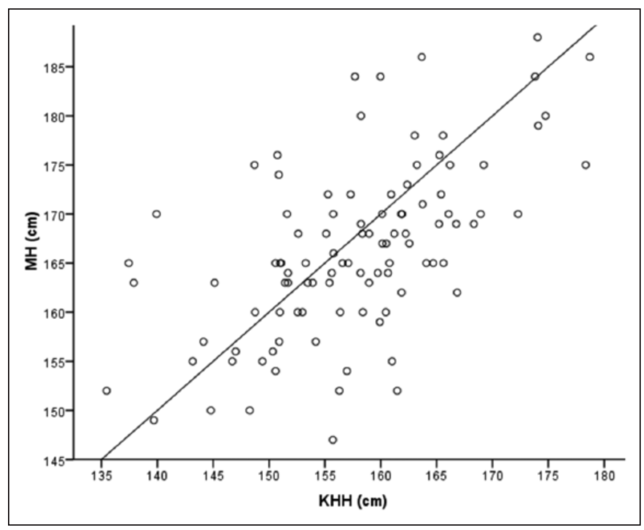

Figure 2. Scatter plot showing the correlation between measured height (MH) and height estimated from knee height (KHH; equations proposed by Chumlea et al[20]). $r = 0.592$ ($P < .001$).

Because there was a significant association between the differences and the averages (bias: −0.04 cm, $P < .001$), we decided that the relationship between averages and differences (estimates of maximum differences) should be expressed according to a line of linear regression. Figure 4 shows the concordance and confidence intervals for the difference (cm) between MH and ULH (y) and the average (cm) between MH and ULH (x). The linear regression equation, $y = -99.6 + 0.6 \times x$, suggests that the difference between MH and ULH is

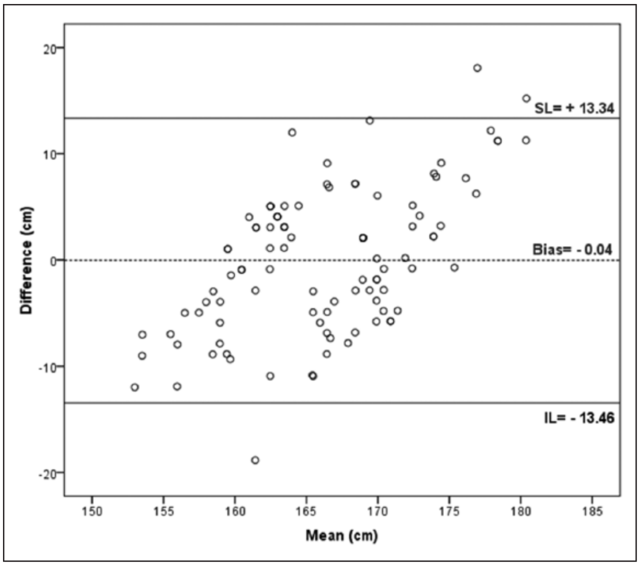

Figure 3. Bland-Altman plot showing the agreement between measured height and height estimated from ulna length. The dotted line indicates bias, and the continuous lines indicate the limits of agreement. IL, inferior limit; SL, superior limit.

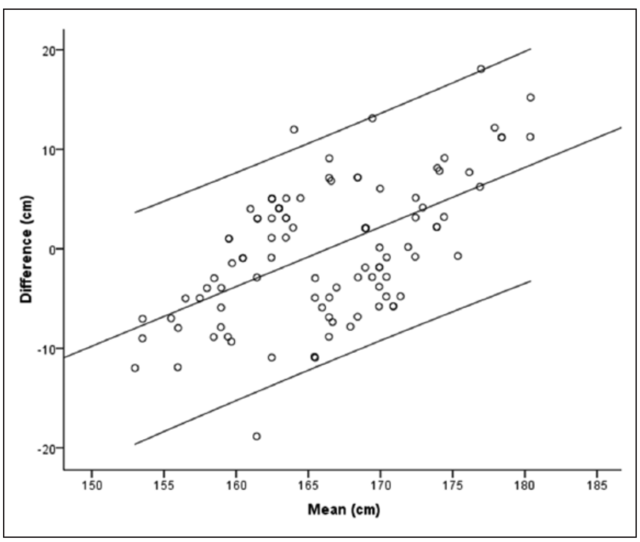

Figure 4. Concordance and confidence intervals for the differences (y) and the means (x) between measured height and height estimated from ulna length. Linear regression equation: $y = -99.6 + 0.6 \times x$; $R^2 = 0.312$.

dependent on MH. For example, the difference between the proposed mathematical formula (ULH) and the standing real height (MH) of an individual at 155 cm would be −6.6 cm; for an individual with 167 cm of body height, it would be 0.6 cm; and for an adult measuring 189 cm, the difference would be 13.8 cm.

A significant difference between MH and KHH averages was observed (difference: 8.69 cm, $P < .001$). However, this

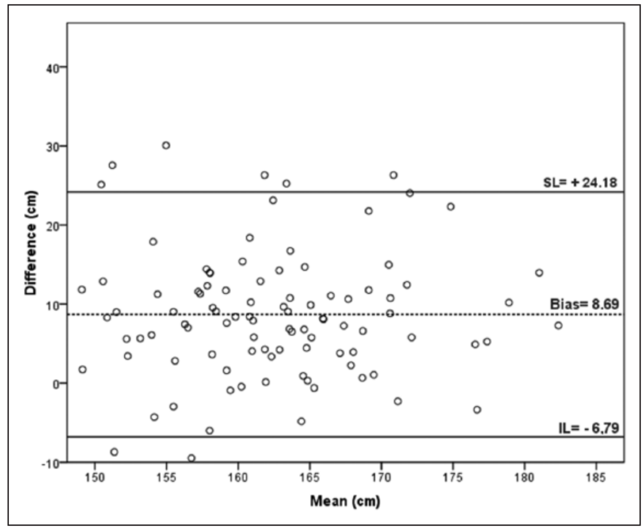

Figure 5. Bland-Altman plot showing the agreement between measured height and height estimated from knee height. Dotted line indicates bias, and continuous lines indicate limits of agreement. IL, inferior limit; SL, superior limit.

bias was not significant in the linear regression analysis (P = .98), suggesting that it is proportional, as observed in Figure 5. The limits-of-agreement interval on the Bland-Altman plot was higher when compared with ULH.

Discussion

This study evaluated the use of UL as a method to estimate the height of critically ill patients. Because performing the height measurement through the gold standard (upright posture) is often very difficult in this setting, our main goal was to develop a mathematical formula for height estimation with UL.

We decided to exclude both the recumbent height measurement—because it is unfeasible for many critically ill patients—and the patient's reported body height, due to the trend for height reduction related to the aging process and the fact that many individuals ignore their actual height (ie, many elderly remember only their height measured at youth).[21]

Due to alternative methods for estimating height, some equations based on UL have been explored among different populations, such as the British and Portuguese,[14] Turks,[13] Sudanese,[22] Indians and Iraqis,[12] and Sri Lankan,[11] as well as with American[9,23] and Australian[5] pediatric populations. However, these mathematical formulas were created for healthy populations and were based on different ethnicities.[10] Regression analysis is considered a reliable tool for height estimations, and one of the advantages of this method is to create an equation with a single body measure. However, due to its less accurate predictive capability in the face of great variability among the body proportions of different populations, it is suggested that each predictive equation be specifically created for the population in question.[22]

Using UL, we identified an agreement between the height estimated by our mathematical formula and the patient's MH, despite some reservations. We observed that the estimation resulting from the mathematical formula tends to be influenced by extremes; that is, for tall individuals, it tends to overestimate stature, while for those of very low stature, it tends to underestimate it. In sum, its utility is limited at the extremes of height. The equation based on KH for height estimation presented a systematic bias; that is, KHH was not influenced by extremes, and the bias is uniform among patients, being less influenced by very tall or very short individuals. Despite the large limits-of-agreement interval observed in our study regarding ULH (13.34 to −13.46 cm), it is lower than that observed in a study conducted in a Brazilian emergency room (14.39 to −13.69 cm), which used the MUST protocol to evaluate the values of estimated height with UL.[16]

In a study performed in the ICU of a European university hospital,[6] researchers assessed whether different mathematical formulas of height prediction validated among healthy populations would be accurate for critically ill patients, and their correlation between the height estimated through UL and MH was lower than the correlation observed in our study ($r = 0.51$). It reinforces the importance of elaboration and validation of specific predictive equations for each population. Ahmed[22] assessed the height prediction of a Sudanese adult population through the long bones of upper limbs; with an equation based on UL, a positive correlation was observed in relation to MH ($r = 0.73$ for men and $r = 0.72$ for women), showing that the use of this body compartment may be a feasible alternative for estimating height, for both men and women.

In a study with critically ill patients performed in a Swiss university hospital,[4] MH and the Chumlea method for estimating height were compared. Similar to our results, a satisfactory correlation was observed between body heights estimated by KH and MH; however, it presented an overestimation of height values, with a varied and randomly distributed dispersion.

Al-Wasfi and Puranik[12] assessed the height prediction of 196 healthy Indians and Iraqis, using measurements of 2 body parts: fibula and ulna. Based on that, 3 equations were created: first, using fibula length; second, UL; third, both. The best regression model was the one based on both variables (fibula length + UL), showing a strong and significant correlation ($r = 0.87$, $P < .001$). The predictive formula based on only UL showed moderate correlations for Indians and Iraqis ($r = 0.62$ and $r = 0.59$, respectively), supporting our results.

Our study had some limitations. Among them, we mention the sample size, because the enrollment of a larger number of individuals could imply a bias decrease. However, our results are consistent with other studies assessing healthy populations. In our study, we evaluated only patients whose MH was listed on the medical record, and such procedures are not always performed in hospitals—underreporting of patients' weight and height data is not uncommon. Although professionals were previously trained, we cannot warrant that the protocol for height measure was homogenized among all who were responsible for measuring patients' height in the hospital admission units.

Conclusion

The mathematical equation based on UL to predict body height that was developed in this study seems to provide good standing height estimation for critically ill patients. We suggest, however, that our results be replicated in other populations of hospitalized individuals, to reinforce our findings. Regarding next steps of our research, we intend to validate our equation in a larger population of critically ill patients.

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Statement of Authorship

A. Marcadenti, D. Fernandes, and E. I. Rabito equally contributed to the conception and design of the research; M. Rosa contributed to the design of the research; M. Rosa, M. L. Oliveira, and M. S. Tarnowski contributed to the acquisition of the data; A. Marcadenti, E. I. Rabito, and V. N. Hirakata contributed to the analysis and interpretation of the data; and M. S. Tarnowski and A. Marcadenti drafted the manuscript. All authors critically revised the manuscript, agree to be fully accountable for ensuring the integrity and accuracy of the work, and read and approved the final manuscript.

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