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Ulna length predicts height measured by stadiometer among adults attending the University of Cape Coast Hospital, Ghana

Kasim ABDULAI [1*], Safianu O ALEBOKO [2], Emil A KAFUI [1], Seidu A MOHAMMED [1], Gifty KORSAH [1], Fatimatu SALIFU [1], Olivia O OTCHIE [1], Ivan ADDAE-MENSAH [1], Sylvester O GYEABOR[4], Abdul-Malik Bawah[1]

[1] Department of Nutrition and Dietetics, School of Allied Health Sciences, University of Cape Coast, Cape Coast, Ghana; [2] Department of Nutritional Sciences, Oklahoma State University, United States; [3] Tamale Teaching Hospital, Tamale, Ghana; [4] KAAF University College, Budumburam, Ghana

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Abstract

Background: The Malnutrition Universal Screening Tool (MUST) suggests the use of ulna length as an alternative method for determining patients' height when measured standing height is not possible to obtain. Ulna length has been studied as a potential surrogate measure for height estimation in various populations.

Objective: This study evaluated the agreement between height predicted by ulna length using the Elia (2003) predictive equation and height measured by stadiometer among adults in the University of Cape Coast Hospital (UCC-H) Outpatient Department (OPD) in Ghana.

Methods: This cross-sectional study sampled 402 adults from the UCC-H OPD in Ghana. Data on anthropometric measurements, including height and ulna length, were collected. R version 4.3.2 was used for statistical computing and graphics. Measurement error, error range, limits of agreement, and the Bland-Altman plot were used to assess the agreement between standing height and the height predicted by ulna length. Sex-stratified analyses and internal validation were also performed.

Results: The mean difference (bias) between predicted and measured height was an overestimation of +14.6 cm (95% CI: 13.6 cm,15.5 cm). The 95% Limits of Agreement (LOA) were wide, ranging from −4.9 cm to +34.1 cm. Linear regression showed a strong correlation (R2 = 0.86), but a Bland-Altman analysis revealed the lack of clinical interchangeability. The analysis for proportional bias was non-significant (p = 0.18). Sex-specific equations materially reduced the bias and LOA, although the agreement remained clinically unacceptable.

Conclusion: The Elia (2003) equation significantly and systematically overestimates the height of this sampled adult OPD population. The wide LOA indicates that the predicted height is not clinically interchangeable with measured height, which could lead to substantial misclassification of Body Mass Index (BMI). We recommend the development and external validation of population-specific equations before any routine clinical use in this setting.

Keywords: Height, ulna length, stadiometer, agreement, prediction

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INTRODUCTION

Accurate height measurement is essential for numerous public health and clinical applications, including the calculation of body mass index (BMI), ideal body weight (IBW), creatinine height index, and basal metabolic rate. These indicators are widely used in the assessment of nutritional status, estimation of energy requirements, and clinical decision-making in healthcare settings [1]. Reliable height measurements, therefore, play a critical role in nutritional screening, monitoring growth and development, and identifying individuals at risk of malnutrition or chronic diseases. However, obtaining

* *Corresponding author*
Email: Kasim.abdulai@ucc.edu.gh

accurate standing height measurements can be challenging in cases where patients are unable to stand upright and unassisted. This particular group includes individuals who are frail, critically ill, or dealing with limb or vertebral column deformities or neuromuscular weakness [2].

Alternative methods for determining height involve the use of indirect approaches, such as measuring long bones and incorporating these measurements into height estimation equations [3]. These approaches encompass demi-span and arm-span measurements, knee height, and percutaneous measurement of the ulna. Various studies have investigated the validity and applicability of long-bone measures as potential indirect height estimates, using mathematical equations derived from regression models [4]. It is important to note that these equations have not been externally validated; therefore, their validity in other populations and samples remains unknown. When measuring additional body dimensions for height calculation, practicality becomes a crucial consideration, especially in the case of bedbound or frail individuals. In such situations, procedures that entail minimal effort from the subject and require limited undressing prove more advantageous.

Consequently, the measurement of ulna length emerges as a more practical approach compared to arm span or demi-span, particularly when a patient is unable to extend or hold their arms for measurement, as noted by Madden and Smith (2016) [3]. It is noteworthy that currently, no equations have been specifically developed and widely adopted for the Ghanaian population. Only two published studies have explored the applicability of certain existing equations to predict height in Ghana [5,6]. Given that discrepancies in height measurements can be influenced by factors such as age, sex, and ethnicity, it is essential that height prediction equations based on ulna length be specific to age, sex, and ethnicity and be validated in populations. In Ghana, ulnar length measurement using the equation recommended by the Malnutrition Universal Screening Tool (MUST) is one of the most widely used techniques for predicting height in a clinical setting. However, no scientific evidence is available on the validity and applicability of this approach to guiding healthcare workers. The objective of this study was to evaluate the agreement between height predicted from ulna length using the Elia [7] predictive equation and height measured with a stadiometer among adults attending the University of Cape Coast Hospital, Ghana.

MATERIALS AND METHODS

Study design

This study employed a cross-sectional design and selected 402 adults through purposive sampling at the University of Cape Coast Hospital in Cape Coast, Ghana.

Study sites

The study was conducted at the outpatient department (OPD) of the UCCH in Cape Coast, Ghana. The OPD at UCCH serves as a secondary reference center for students, staff, and members of the University of Cape Coast (UCC) adjoining communities.

Inclusion and exclusion criteria

Inclusion criteria encompassed skeletally stable adults aged 18–65 years; this was to ensure elimination of long-bone maturation and degeneration effects on the study outcome. The ability to stand upright without assistance for all measurements to be taken accurately was also required for recruitment into the study. Exclusion criteria included individuals unable to stand unassisted, those taking medication affecting bone development, and individuals with spinal curvature or injuries affecting posture.

Recruitment and participant flowchart

A total of 500 individuals were initially screened for eligibility. Of these, 50 declined the initial screening. The remaining 450 were assessed for eligibility; 15 were excluded (10 fell outside the age range of 18–65 years, and 5 presented with amputations or deformities). Consequently, 435 individuals met the inclusion criteria. A further 33 individuals refused participation at the consent stage. The final sample consisted of 402 enrolled participants who provided complete data for analysis.

Instruments

The Open Data Kit tool was used for data collection, covering sociodemographic and anthropometric measurements, including standing height and ulna length. An interviewer-administered questionnaire was designed to collect sociodemographic data. A calibrated mobile Seca stadiometer was used to measure the standing height, and a non-stretchable measuring tape was used to measure the ulna length of the study participants.

Data collection procedures

Informed consent was first obtained from the study participants. The sociodemographic information of the study participants was recorded through an interview. All anthropometric measurements were taken by a single trained assessor to eliminate inter-observer variability. Standing height was measured following the standardised “stretch” technique [8]. Participants were asked to remove their shoes. A calibrated, mobile, freestanding Seca stadiometer was used, and measurements were recorded to the nearest 0.1 cm. Ulna length was measured following published techniques [8–10]. The left ulna length was measured twice by the same assessor from the tip of the olecranon process (elbow) to the tip of the styloid process (wrist) with the elbow flexed at 90 degrees [9]. A non-stretchable measuring tape was used to measure the ulna length of the study participants. The average of the two measurements was recorded in centimetres (cm) [8]. Intra-rater reliability was confirmed through pilot testing prior to data collection, yielding an Intraclass Correlation Coefficient (ICC) of 0.98 (95% CI: 0.96, 0.99) for the ulna measurement, calculated using a Two-Way Mixed Effects, Absolute Agreement, Single Rater model, indicating excellent reliability [10].

Prediction equation

Height was estimated using the general prediction equation described by Elia (2003), which is commonly adopted in the MUST protocol: Predicted Height (cm) = (4.68 × Ulna Length) + 65.7

Data analysis

R version 4.3.2 was utilised for statistical analysis and graphics. The Elia (2003) equation was used to calculate predicted height. Agreement between measured and predicted height was assessed using the Bland-Altman method. The 95% Limits of Agreement (LOA) were calculated as the mean difference ±1.96 × SD of the differences. The 95% Confidence Intervals (CIs) for the Mean Difference and the LOA were computed using the Bland-Altman delta method. The priori clinical tolerance limit for height estimation was set at ±5 cm to minimise the risk of significant BMI misclassification and medication dosing errors. Proportional bias was tested by regressing the difference (Predicted Height – Measured Height) on the mean height ((Predicted Height + Measured Height)/2). Linear regression diagnostics, including residual plots and the Breusch-Pagan test for heteroscedasticity, were performed in recognition of model assumptions. Cook's distance was used to identify influential outliers.

The Bland-Altman analysis and linear regression were repeated after stratifying the sample by sex. The overall and sex-specific regression models were subjected to internal validation using a 1,000-sample bootstrap procedure to estimate the optimism-corrected R-squared, Standard Error of Estimate (SEE), and bias. This validation confirmed minimal optimism; for the locally derived overall model, the optimism-corrected SEE was 4.2 cm (compared to the original 4.13 cm), and the bias remained +14.6 cm.

RESULTS

Sociodemographic and anthropometric characteristics

The study involved a total of 402 participants, comprising 226 males. 36% of the participants were in the 18 – 27-year age range (see Table 1). Ethnic diversity was observed, with Fante being the predominant group at 62%. The analysis of anthropometric measurements showed significant differences between males and females. The median standing height for males was 170 cm, while females had a median height of 159 cm. Ulna length and predicted height also exhibited gender variations, with males having higher median values compared to females. These findings were statistically significant, with p-values < 0.001 for all measurements.

Correlation between ulna length and standing height

Figure 1. presents data illustrating the correlation between the ulna length and standing height among two groups differentiated by sex—females and males. A positive correlation is apparent in both groups, suggesting that individuals with longer ulna measurements typically have greater standing heights. The males, represented by blue dots, generally show higher values in both ulna length and standing height compared to the females, indicated by red dots. This distinction aligns with common biological differences in stature between the sexes. The data points are spread in a way that indicates a consistent relationship across the sampled population, with some variability and potential outliers that deviate from the trend.

Actual standing height and predicted height

Figure 2. summarises the relationship between actual standing height and predicted height, segregated by sex—females in red and males in blue. The graph suggests a

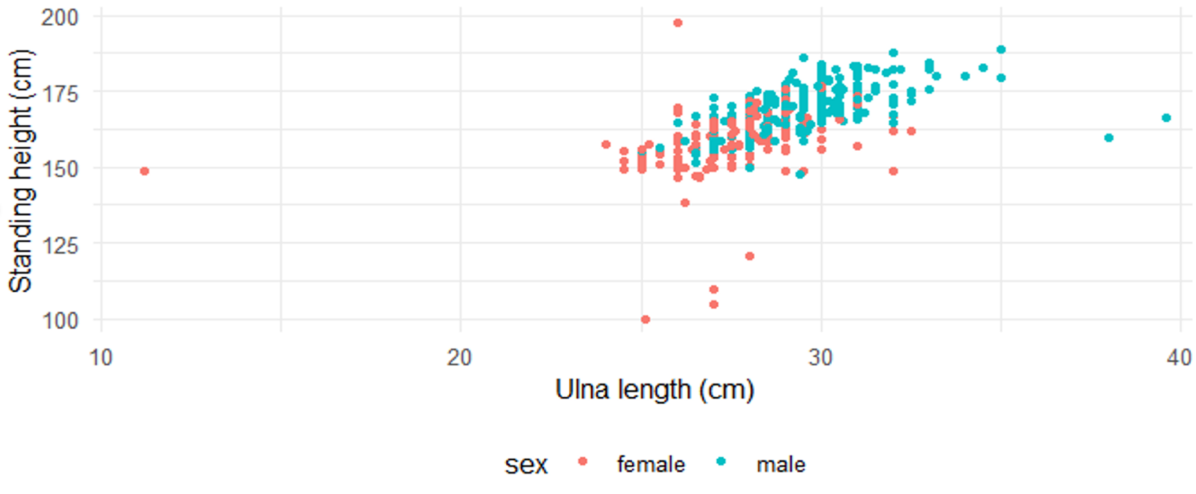

Figure 1. Scatterplot of Ulna length by Standing Height, stratified by sex. Males are represented by blue dots and females by red dots. A positive correlation is evident in both groups, with males generally showing higher values for both measurements

strong positive correlation for both sexes, where the predicted heights closely match the actual standing heights. This tight cluster of data points along the line of equality suggests that the predictive method for height based on ulna length is relatively accurate for this population sample. The sexes are distinguishable, with males tending to have both higher actual and predicted heights, consistent with the typical differences in stature between sexes. The concentration of points along the diagonal indicates that the prediction error is small for most of the range, though there are some deviations.

Association between anthropometric data

The correlation (Table 2) displays Spearman correlation coefficients among predicted height, standing height, and ulna length, with a sample size of 402. The matrix shows strong positive correlations between all three measurements. Specifically, the correlation between predicted height and standing height is very high at 0.91, indicating a strong agreement between these two measures. The ulna length has a strong correlation of 0.7 with standing height, which may suggest that ulna length is a good predictor of standing height. The matrix uses a Holm adjustment for significance, and all shown correlations are significant at $p < 0.05$, suggesting that the relationships are statistically robust.

Linear regression analysis and agreement metrics (ICC)

A simple linear regression model was derived from the data to predict height (cm) from ulna length (cm): Height (cm) = 17.5 + 5.1 × Ulna Length (cm). The model had a high coefficient of determination (R2) of 0.83, and the Standard Error of the Estimate (SEE) was 4.13 cm. The Intraclass Correlation Coefficient (ICC) was 0.90 (95% CI: 0.88,

Table 1. Sociodemographic characteristics and anthropometric measurements of the study participants

Characteristic	Overall, N = 402[1]	Male, N = 226	Female, N = 176	p-value[3]
Age (years), n (%)				
18-27	145 (36%)	79 (35%)	66 (38%)	0.500
28-37	56 (14%)	31 (14%)	25 (14%)	
38-47	95 (24%)	60 (27%)	35 (20%)	
48-65	106 (26%)	56 (25%)	50 (28%)	
Ethnic group, n (%)				
Akan	79 (20%)	50 (22%)	29 (16%)	0.069
Ga/Dangme	8 (2.0%)	3 (1.3%)	5 (2.8%)	
Ewe	25 (6.2%)	17 (7.5%)	8 (4.5%)	
Fante	249 (62%)	128 (57%)	121 (69%)	
Mole-Dagbani	2 (0.5%)	2 (0.9%)	0 (0%)	
Krobo	0 (0%)	0 (0%)	0 (0%)	
Hausa	15 (3.7%)	8 (3.5%)	7 (4.0%)	
Others (Specify)	24 (6.0%)	18 (8.0%)	6 (3.4%)	
Standing height, Median (IQR)	166 (158, 172)	170 (166, 175)	159 (154, 164)	<0.001
Ulna length (cm), Median (IQR)	28.50 (27.50, 30.00)	29.50 (28.43, 30.58)	27.70 (26.50, 28.50)	<0.001
Predicted height (cm), Median (IQR)	180 (173, 187)	185 (181, 189)	173 (169, 175)	<0.001

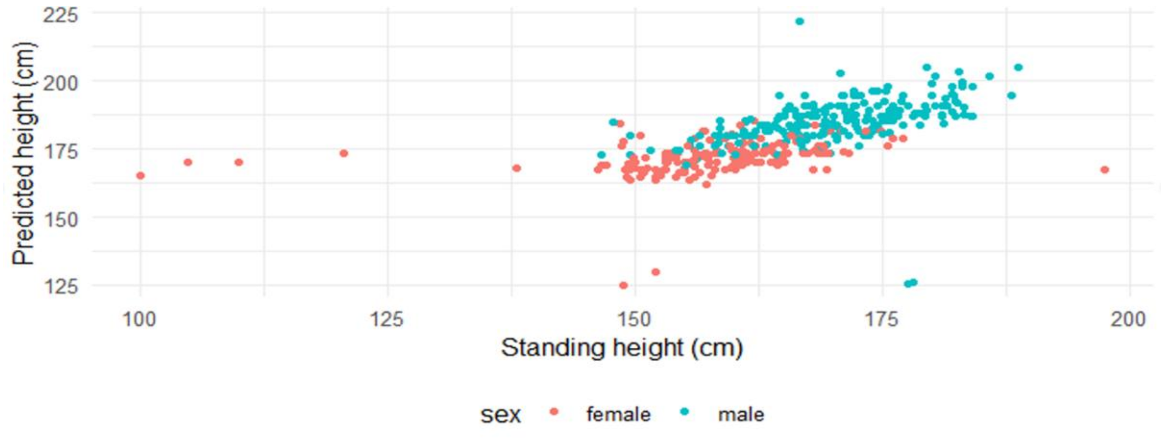

Figure 2. Scatterplot of standing height by predicted height, stratified by sex (n = 402). Males (n = 226) are represented by blue dots and females (n = 176) by red dots. The graph shows a strong positive correlation, though many data points fall above the line of equality, visually suggesting an overestimation of predicted height.

0.92), calculated using a Two-Way Mixed Effects, Absolute Agreement, Single Rater model, indicating excellent reliability for ranking (Table 2). Residual plots confirmed a reasonably normal distribution of residuals, and the Breusch-Pagan test for heteroscedasticity was non-significant (p = 0.45), indicating that the assumption of constant variance was upheld. The regression of the difference on the mean height yielded a slope of 0.051 with a p-value of 0.18. Since the p-value was above 0.05, no statistically significant proportional bias was detected, and therefore no transformation was necessary for the Bland-Altman analysis. Eight influential outlier data points (approximately 2.0% of the sample) were identified outside the LOA range. Excluding these points in a sensitivity analysis resulted in a reduced Bias of +13.5 cm and a narrower LOA range (LOA: −2.1 cm to +29.1 cm). However, the essential conclusion of poor agreement remained unchanged.

Sex-stratified analysis

Given the significant differences in median measured height and ulna length between the sexes (Table 3), a sex-stratified analysis was performed, yielding improved prediction metrics. The sex-specific equations materially reduced the magnitude of bias and narrowed the LOA range compared to the overall model. The Male-Specific equation showed the lowest bias and best agreement metrics for this population.

Consequences of theoretical BMI misclassification

We recognise that the absence of measured weight in this study prevents the calculation of a full BMI misclassification contingency table for our cohort. However, the clinical impact of the observed mean systematic height overestimation (+14.6 cm) can be quantified using theoretical examples, demonstrating the severe consequences for nutritional screening and drug dosing.

Table 2. Summary of agreement and prediction metrics

Metric	Value	95% Confidence Interval (CI)
Bland-Altman Mean Difference (Bias)	+14.6 cm	13.6 cm, 15.5 cm
Bland-Altman Lower Limit of Agreement (LOA)	−4.9 cm	−7.2 cm, −2.5 cm
Bland-Altman Upper Limit of Agreement (LOA)	34.0 cm	31.7 cm, 36.3 cm
Total Error Range (LOA Range)	38.9 cm	
Intraclass Correlation Coefficient (ICC)	0.9	0.88, 0.92
Linear Regression R2 (Ulna → Height)	0.83	
Standard Error of the Estimate (SEE)	4.13 cm	

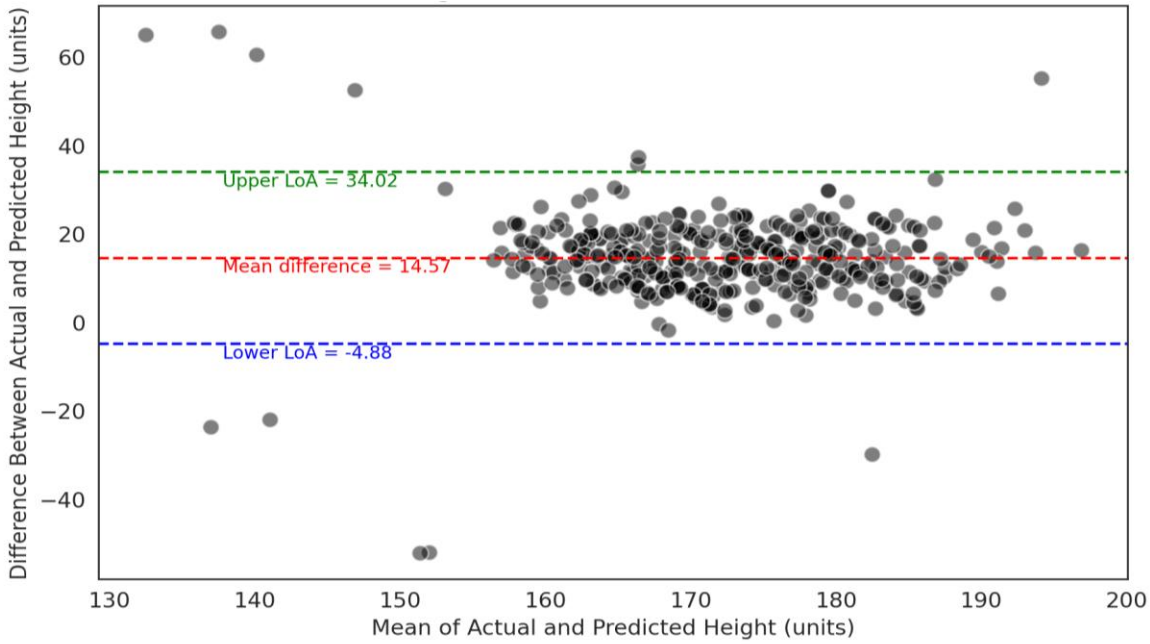

Figure 3. Bland-Altman Plot of agreement between measured and predicted height (n = 402). The plot shows the difference (Predicted - Measured Height) against the mean of the two measurements. The solid red line indicates the mean difference (Bias = +14.57 cm), and the dashed lines represent the 95% Limits of Agreement (Lower LOA: −4.88 cm; Upper LOA: +34.02 cm).

Table 3. Summary of sex-stratified agreement and local prediction metrics

Metric	Overall Model (n = 402)	Male-Specific Model (n=224)	Female-Specific Model (n=178)
Prediction Equation	Height = 17.5+5.1×Ulna	Height=10.3+5.4×Ulna	Height = 22.9+5.0×Ulna
Bias (cm)	+14.6 cm	+1.5 cm	+4.2 cm
95% CI for Bias	13.6 cm,15.5 cm	0.7 cm,2.2 cm	3.1 cm,5.3 cm
LOA Lower Limit (cm)	−4.9 cm	−7.7 cm	−7.3 cm
LOA Upper Limit (cm)	+34.1 cm	+10.6 cm	+15.8 cm
R2	0.86	0.88	0.84
Standard Error of Estimate (SEE) (cm)	4.13 cm	3.5 cm	3.9 cm

The Bland-Altman analysis
The Bland-Altman analysis for the overall sample (N=402) is presented in Figure 4. The Mean Difference (or Bias) g reflects the average discrepancy, which was +14.6 cm (95% CI: 13.6 cm, 15.5 cm). This indicates a significant and systematic overestimation of measured height by the Elia (2003) equation in this population. The 95% Limits of Agreement (LOA) were wide, ranging from −4.9 cm (95% CI: −7.2 cm, −2.5 cm) to +34.0 cm (95% CI: 31.7 cm, 36.3 cm). Visual inspection confirmed the distribution of differences was approximately normal. As confirmed by regression analysis (p = 0.18), there was no statistically significant proportional bias, so no data transformation was required. While Figure 3 plots the entire sample, it obscures important differences between sexes; the full sex-stratified analysis (Table 3) revealed that this bias was different for males (+1.5 cm) and females (+4.2 cm) when using locally derived equations.

DISCUSSION

This study aimed to evaluate the agreement between height predicted by ulna length and actual measured height in adults in Ghana. While several studies [3,4,11] have explored similar methodologies, the application of the MUST-recommended (Elia 2003) equation [7] in combination with stadiometer measurements has not been extensively examined in Ghana. This gap in research underscores the importance of this study in contributing to a more comprehensive understanding of height estimation methods in different populations. Our research indicated a notable overestimation in height prediction using ulna length, though most data aligned with the Limits of Agreement, suggesting a reasonable level of reliability for this method in the Ghanaian context. This general trend of overestimation mirrors findings in regions like Maharashtra and Gujarat [3,12], but the extent of bias and measurement error in our study was more pronounced. For instance, the systematic bias reported (+14.6) is substantially higher than the ≈5 cm bias observed in some Nigerian and other Ghanaian studies that tested similar methods [13], highlighting significant regional anthropometric differences. Furthermore, our study's findings of significant gender differences in ulna length and height prediction resonate with those from Indian populations [14,15]. This distinction between male and female measurements underlines the importance of developing gender-specific models for height prediction, particularly in clinical settings, a recommendation supported by research conducted in Ghana and Nigeria [16]. While the high ICC (0.90) suggests excellent reliability for ranking individuals by height, the large mean bias and wide LOA confirm that the Elia equation is not appropriate for clinical practice where absolute accuracy is needed [16].

The larger margin of error in height prediction observed in our study, compared with other models tested in the Ghanaian population [13], highlights the inherent variability of anthropometric measurements across diverse subgroups within the same region. This variability suggests the need for more localised or population-specific prediction equations, a recommendation that aligns with findings from studies in distinct regional populations [17]. The development of such tailored prediction models is not just a statistical endeavour but carries significant implications for patient care in Ghana. Accurate height estimation is crucial in clinical settings for dosing medications, nutritional assessment, and designing medical equipment.

A systematic overestimation of 14.6 cm and an error range of ≈39 cm are clinically unacceptable, as this magnitude of error would result in misclassification of BMI categories (e.g., from normal to overweight) and lead to serious errors in medication dosing for drugs that require body surface area (BSA) calculations [18]. Therefore, our findings underscore the importance of incorporating regional anthropometric diversity into clinical practices to enhance the precision and effectiveness of patient care. Given this large, systematic bias, clinicians should not simply subtract the bias from the predicted height; rather, a novel, locally derived equation, such as the one derived from this sample (Height = 17.5 + 5.1 × Ulna Length) or alternative height estimation methods, must be used. The use of ulna length for height estimation, particularly vital in clinical scenarios where direct height measurement is impractical, calls for significant improvements in existing prediction models to boost their accuracy. The critical nature of precise anthropometric measurements in clinical and medico-legal contexts, as highlighted in relevant studies [3], further emphasises this need. A notable limitation of our study is the specific demographic characteristics of our sample, which may not fully represent the diverse Ghanaian population. This limitation suggests the importance of future research incorporating a broader and more varied sample. Additionally, exploring other anthropometric measurements could provide alternative or complementary methods to enhance the accuracy of height prediction, thereby catering to a more diverse patient population and refining clinical and forensic practices.

The high coefficient of determination ($R^2 = 0.86$) and the high ICC (ICC = 0.90) confirm a strong relationship between ulna length and measured height. However, it is critical to distinguish between correlation (ranking or consistency) and agreement (interchangeability). A strong correlation only suggests that individuals with longer ulnae are likely taller (good ranking); it does not imply that the predicted height can be used interchangeably with the measured height for clinical purposes. The large positive bias of +14.6 cm reveals a significant systematic overestimation of height by the Elia equation in this single-site Ghanaian OPD population [19]. The high level of bias is likely due to the application of a European-derived equation to a population of different ethnicities and body proportions. The ethnic composition, predominantly Fante in this single-site sample, may contribute to the differences observed. Studies from other West African populations [20] and South African validation studies [14,21] have similarly reported poor agreement, emphasising the need for population-specific equations due to variations in trunk-to-limb ratios across different ethnicities.

The findings must be interpreted in light of the following limitations. The use of a purposive, single-site OPD sample limits the external generalizability of the findings to the wider Ghanaian population. The sample size was based on convenience rather than a formal pre-study calculation to achieve precise LOA. The measurements were taken by a single assessor, which minimised inter-rater error but means the reported excellent reliability might not translate easily to multi-centre studies. The single measurement time of day minimises the measurement order effect but does not entirely rule it out. The locally derived equations (overall and sex-specific) are exploratory and require external validation on independent samples from other regions of Ghana before any recommendation for routine clinical adoption can be made. The inclusion criteria (18–65 years) exclude elderly populations, where height estimation is often most needed. Therefore, the findings and the derived equations may not be applicable in geriatric settings.

Conclusion

The observed systematic overestimation of height (+14.6 cm) using the Elia ulna length equation [7] and the wide limits of agreement highlight the clinical unsuitability of this equation in this single-site Ghanaian OPD population. The magnitude of this error is significant enough to cause a high rate of BMI misclassification and serious risks in medication dosing. The locally derived equations are exploratory only and should not be used for routine clinical substitution without subsequent external validation. Future research should be directed towards creating and refining models specifically designed for the Ghanaian population and validated on independent, external samples. These models should take into account gender differences and other relevant demographic factors that influence height estimation. The findings caution healthcare practitioners against the uncritical application of height prediction models developed for different populations. Instead, they advocate a concentrated effort to develop and implement externally validated, population-specific equations.

DECLARATIONS

Ethical consideration

This study obtained ethical approval from the Institutional Review Board (IRB) of the University of Cape Coast (UCCIRB/CHAS/2023/200). All participants provided informed consent before their inclusion in the study.

Consent to publish

All authors agreed on the content of the final paper.

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None

Competing Interest

The authors declare no conflict of interest

Author contribution

SOA, KA, GK, and FS conceptualised and designed the study. SOA, GK, FS, and OOO implemented the research. SOA, SAM, EAK, and KA conducted the data analysis. SOA, SAM, EAK, IAM, and SOG drafted the manuscript. All authors reviewed the manuscript and approved the final version.

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Availability of data

Data is available upon request to the corresponding author.

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