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A Libyan Model for The Estimation of Personal Stature based on Ulna Length

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Research Article

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Ethics Statement: This study was reviewed and approved by the Subcommittee on Bioethics ([illegible]) at Al-Asmarya Islamic University. The approval code is NBC015. The study was conducted in accordance with the ethical standards of the university and relevant guidelines for human research.

A Libyan Model for The Estimation of Personal Stature based on Ulna Length

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Abstract:

Background: Population-specific regression equations play a crucial role in forensic evaluation. The regression equation determined by analyze the correlation between ulnar length and estimated stature.

Aims: To determine Libyan-specific regression equations through study the correlation between ulnar length and estimated stature.

Settings and Design:

Original article, Cross sectional study (Observational study)

Methods and Material: Ulnar length measurements with participant stature were obtained from a sample of Libyan 4th year medical students. There are typically differences in limb proportions between males and females. Therefore, the measurements were divided according to sex, and statistical regression models were developed for each sex individually.

Statistical analysis used: The obtained data were computed and analyzed with MATLAB

Results:

this article confirmed a positive and significant statistically correlation between ulnar length and estimated stature in both female and males, with difference between both gender, consistent with previous studies in other populations. However, the strength of the correlation and the slope was different from those of several published studies, indicating the importance of population- and gender-specific formulae.

Conclusions: The Libyan model study confirmed that ulnar length is a reliable predictor of personal stature, supporting its use in forensic applications and clinical evaluation.

Key-words:

Libya; Stature Estimation; Ulnar length; Height; *Regression equations.*

Key Messages:

Previous studies established that ulna length can be used as reliable indicators for estimating stature. up to now there is no study evaluated the relationship between ulna length and stature in the adult Libyan population. our aim to fill this gap and provide Libyan-specific regression formulas for estimating stature.

Introduction:

Identifying human bones is a key aspect of forensic work. Constructing a biological profile is important for the identification process. The biological profile includes details such as sex, age at death, height, and unique features. This speeds up the identification process. Together with DNA and dental checks, the biological profile helps identify the person. There are different ways to estimate stature from skeletal bones. These methods depend on completing of the skeletal bones, their population they belong to it, and the measurement techniques used. (1)

Over the past few years, many countries have conducted researches on stature estimation, focusing on specific areas. These studies frequently specified the age group and sex of the individuals in their samples. It is widely recognized that factors such as sex, age at death, and ethnicity significantly affect height estimation, and the necessity of accounting for these factors has been underscored in multiple studies. (1)

The anatomical method directly rebuilds stature by adding the dimensions or heights of adjacent skeletal elements from the skull to the foot. (2) This method explains the individual variation in body proportions and is considered superior when nearly complete skeletons are available for studies. Raxter et al. revised Fully’s anatomical technique by testing it on a large, ancestrally diverse sample and refining the measurement protocol. When the anatomical method is not applicable due to the absence or fragmentation of bones, mathematical regression equations that rely on the length of separate limb bones are the most prevalent alternative used worldwide. These methods establish a linear correlation between the measured stature and the length of bones, such as the humerus, ulna, femur, tibia, fibula, and hand bones. By applying a general equation, it is possible to estimate a person's height from one or more preserved bone remnants. (1,2)

Early initial work by Pearson (1899) established the first regression formulas, which predict stature using long bone measurements, based on that establishing a specific equation is still

widely used today. However, these equations are often specific to the population. and method techniques can be divided into four main types: (1) methods designed for specific populations or regions; (2) methods that use race-specific formulas following Trotter and Gleser's approach; (3) methods for different decades; and (4) methods for different heights, with formulas for short, medium, and tall people. (3,4)

Practically, most researchers use long bone regression techniques because they are simple and more accurate, especially when the skeleton is incomplete. (5) These regression formulas can vary significantly, especially when used on population with different body proportions. Therefore, it is important to have population specific regression to each population to improve accuracy. (6) additionally, Bidmos proposed that these equations should be updated regularly to keep up with global changes.

Although most researchers consider the femur the most reliable bone for stature estimation, many studies have explored other bones, such as the tibia, ulna, scapula, hand, foot, and other bone remains. (1; 7) Studies have indicated that tibia length can sometimes outperform femoral length in specific populations, although tibia-based equations may be more susceptible to population-specific bias. (1) Research on hand dimensions has revealed a strong correlation with stature, and the combination of hand length and palm length provides reliable predictors in the North Saudi population. (7) In other hand ulnar length has been used for stature estimation and has shown consistent correlation more than that of other long bones. In particular, the measurement of ulnar length offers precise regression equations for estimating stature, similar to the equations obtained using the lengths of other bones, such as the tibia. (8) Similarly, Auyeung showed that estimating stature using the lengths of the fibula and ulna is as accurate as using knee height. Therefore, using ulna length to estimate stature is useful when measuring knee height is difficult or unavailable. (9) Hand and upper limb measurements have emerged as valuable alternatives or supplements for stature estimation in Middle Eastern populations, particularly when long bones are not available.

Studies in different countries like Saudi Arabia and Jordan. (10,11) show a strong link between height and hand dimensions, including hand length, palm length, and hand width. Additionally, personal stature is influenced by nutrition, environment, hormones, and socioeconomic factors. By assessing these factors and by using specific equations designed for each population, researchers can realize growth-related problems. Malnutrition is the main cause of growth failure in the world. Although issues such as malnutrition, chronic infections, and food contamination are not specific to a particular race, their current presence in certain areas has led to changes in population specific equation over time, resulting in ethnic short stature in some individual populations. (12).

Internationally, many countries, including Germany, France, India, Japan, and South Africa, have developed localized stature estimation formulas. (1) For instance, Kornieieva and Elelemi (2016) demonstrated that stature and hand dimensions in the Saudi population closely resemble those observed in the Chinese and Egyptian populations but differ significantly from those in the Australian and Indian populations. This finding supports the need for population-specific stature-estimation techniques. No previous research on this topic has been reported for modern adult Libyan population. Therefore, this study aimed to evaluate the relationship between ulna length and height in Libyan adults and to create regression equations for estimating height based on ulnar length. (10)

Subjects and Methods:

Sample selection

In 2025, a research project was undertaken at the Forensic and Toxicology Medicine Department, College of Medicine, Alasmarya Islamic University, in compliance with the ethical guidelines set by the Alasmarya University Ethics Committee for Human Experimentation. informed consent was obtained from participants. This cross-sectional descriptive study involved 214 healthy Libyan students aged 20–25 years, divided into two groups: 100 men and 114 women. To avoid diurnal variations, all measurements were taken

between 10 am and 2 pm. Participants with visible pathologies or a history of upper limb surgery were excluded. Written informed consent was obtained from all the participants.

Stature measurement

The height of each individual was determined by measuring the distance from the top of the head to the floor while the person stood upright in an anatomical position with the head aligned in the Frankfort plane. The Kinlee height and weight scales was used for measurement. The participants were instructed to stand barefoot on a flat horizontal base, maintaining an erect posture with their back against the stadiometer's vertical board and their head positioned in the eye–ear–eye plane (Frankfurt plane). The measurement was taken from the heel to the vertex by lowering a sliding bar to the top of the head.

The ulna length measurement

The length of the ulna was measured as the linear distance from the tip of the olecranon process to the styloid process when the elbow was completely flexed. (13) A sliding Vernier caliper was used to measure the ulna length.

Statistical analysis methods

We created Statistical regression models to estimate a person's height based on their ulna length. We used MATLAB for all calculations. After working out the basic statistics, differences in ulnar measurements by sex were checked using a paired samples t-test.

Ulna length, which is strongly linked with height, was used in a regression model to find the constant “a” and the regression coefficient “b” for estimating height with the formula S = a + bx, where “x” is a known “independent variable” from hand size. The link between height (dependent variable) and ulna length (explanatory variable) was measured using Pearson’s correlation. Simple and multiple linear regression equations with these variables were suggested to explain the changes in height. The model with the highest “R2” was the best for estimating height. The standard error of estimate (SEE) was determined by comparing the actual height with the height estimated from the regression equation.

Results:

Descriptive Statistics showed that a total of 214 Libyan medical students (100 males and 114 females) participated in the study. The descriptive statistics for height and ulna length, stratified by sex, are presented in Table 1. The mean estimated male stature in native Libyans from Zliten was 177.0 cm, and the mean female stature was 161.3 cm. The mean ulna length and height were significantly greater in males than in females ($p < 0.0001$ for both).

Table 1. Descriptive statistics for height and ulna length by sex

Parameter	Female	Male
Total number (n)	114	100
Height range (cm)	146.2 – 178.6	161.0 – 189.6
Ulna length range (cm)	22.05 – 30.0	25.2 – 33.0
Mean height (cm)	161.3	177.0
Mean ulna length (cm)	26.0	28.32

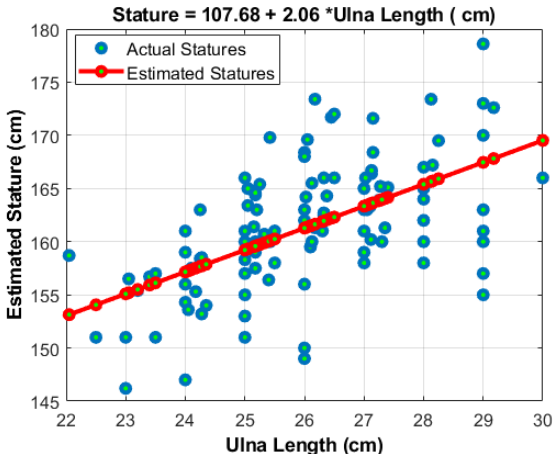
Pearson's correlation coefficient showed a significant positive correlation between height and ulna length measurement in both male and female participants.

In the male group, the analysis revealed a moderate positive correlation ($r = 0.637$, $p < 0.001$). The coefficient of determination ($R^2 = 0.406$) indicated that ulnar length explained approximately 40.6% of the variance in stature in the male group. The regression equation was:

$$\textbf{Stature} = 107.384 + 2.456 \times (\textbf{Ulna length}) \quad (1)$$

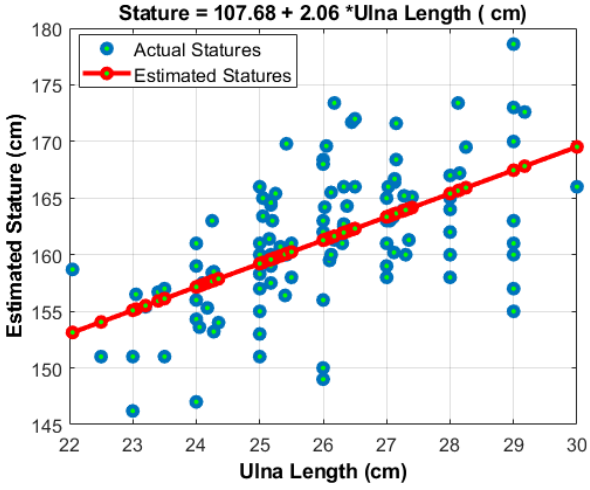
The slope (2.456) indicates that each additional centimeter of ulnar length corresponds to an average increase of 2.456 cm in stature. The model was statistically significant ($p < 0.001$). Figure 1 shows the correlation between estimated stature and ulnar length in males.

Figure 1 showing the correlation between estimated stature and ulna length in male



In female participants, linear regression analysis revealed a moderate positive correlation ($r = 0.587$, $p < 0.001$) between the ulnar length and estimated stature. Ulna length explained approximately 34.5% of the variance in stature ($R^2 = 0.345$). The slope (2.061) indicates that each additional centimeter of ulna length corresponds to an average increase of 2.061 cm in

Figure 2 Showing the correlation between estimating stature and ulna length in female



stature. The model was statistically significant ($p < 0.001$). Figure 2 shows the correlation between estimate stature and ulna length in females. Female regression equation:

Stature = 107.679 + 2.061 × (Ulna length) (**2**)

Ulna length was a better predictor of stature in males than in females within this sample, as evidenced by a steeper slope observed in males, a higher correlation coefficient (0.637 vs. 0.587), and greater explained variance (40.6% vs. 34. 5%). The lower standard error of the estimate (SEE) (±4.45 cm vs. ±4.90 cm) indicates more precise prediction. The comparison between male and female group results illustrated in table 2

Table 2 illustrates the comparison between male and female group results

	Male	**Female**
Regression equation	Stature = 107.384 + 2.456 × (Ulna length)	Stature = 107.679 + 2.061 × (Ulna length)
R^2	0.406	0.345
r	0.637	0.587
SEE	±4.447 cm	±4.897 cm
The slope	2.456	2.061

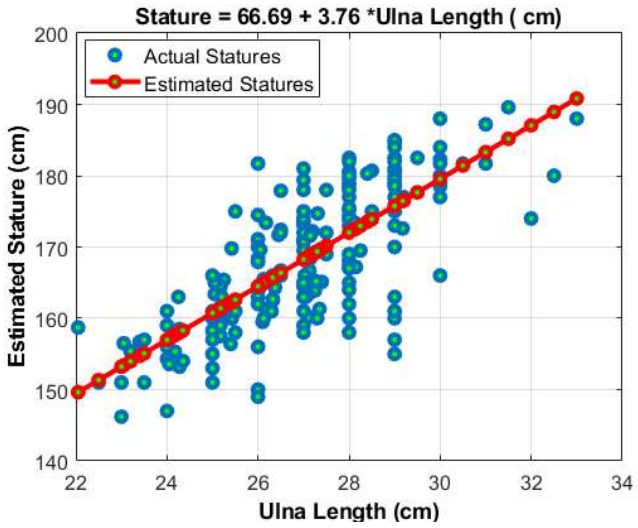
Combined sex-specific equations were statistically valid for Libyan medical students. When males and females were combined (n = 214), the regression equation was as follows:

Stature = 104.924 + 2.343 × (Ulna length) (**3**)

The Correlation between ulna length and estimated stature in the combined female and male groups. shows a strong positive relationship ($R^2 = 0.5793$). However, compared to sex-specific equations (females: Stature = 107.68 + 2.06 × Ulna length; males: Stature = 107.38 + 2.46 × Ulna length), in the combined group, there is a lower intercept and steeper slope, reflecting the combining of two distinct sex-based distributions. The SEE ± 6.3535 cm should be reported as being higher than the separate male or female equations. Thus,

sex-specific stature estimation is preferred, and the combined equation should not be used

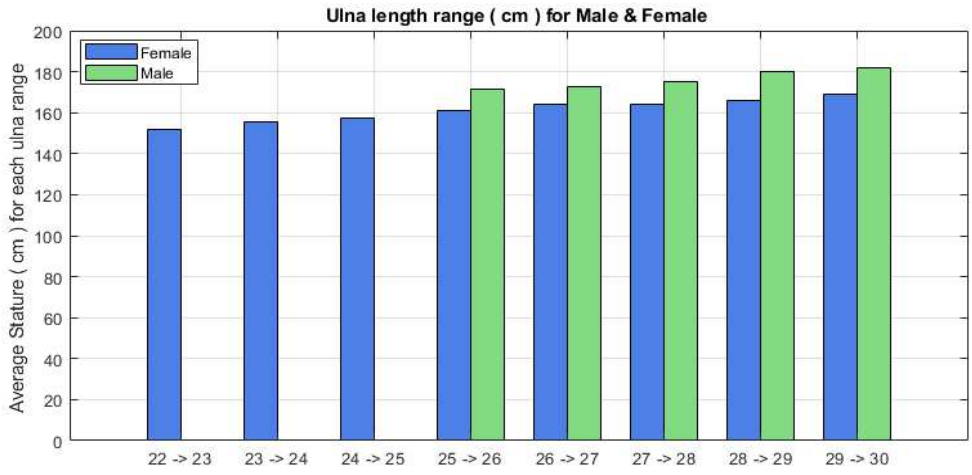
Figure 3 Correlation between ulna length and estimated stature in the combined female and male groups



for forensic or clinical applications without adjustment.

Figure 4 bar chart showing the relationship between ulna length and mean estimated stature in males and females. Both sexes show a positive linear trend. Males have higher mean stature than females. These findings also support that sex-specific regression equations are

Figure 4 showing Relation between ulna length and mean of estimated stature in Males and females



more appropriate than a combined equation for stature estimation from ulnar length.

Discussion:

It is important to have specific formulas for different populations because general formulas can lead to errors. (14) This study aimed to create a formula for Libyans to estimate height from the length of the ulna in adult men and women. We found a significant correlation between ulna length and estimated stature, similar to other studies in different groups. (15; 16;8) However, the strength of this correlation was different for men and women (females: r = 0.587; males: r = 0.637), and the slopes were different from the population in other studies (females: 2.061; males: 2.456). This supports the need for formulas specific to each population and gender.

Table 3 compares the regression equation for the Libyan female model with those from other populations. Our slope (2.061) was considerably lower than those reported for Sri Lankan (3.536), South Indian (3.095), and Pakistani women (5.617). These differences likely reflect population-specific body proportions, particularly limb-to-stature ratios. Libyan females in our sample may have relatively shorter forearms in relation to stature than South Asian populations. The extremely high slope reported by Gul et al. (2020) (5.617) in Pakistani women with an exceptionally high R^2 (0.958) may related to a very homogeneous sample in the sample size of 50 women. (8**)**

Table 3. Comparison of female regression equations across other populations

Study	**Population**	**Equation (stature in cm)**	**r**	**R^2**
Current study	Libyan	107.68 + 2.061 × UL	0.587	0.345
Ilayperuma et al. (2010). (15)	Sri Lankan	68.78 + 3.536 × UL	0.760	0.578
Natarajan et al. (2019). (16)	South Indian	78.06 + 3.095 × UL	0.659	0.434
Gul et al. (2020). (8)	Pakistani	18.56 + 5.617 × UL	0.979	0.958

UL = ulnar length (cm)

Our Libyan male regression equation also shows a lower slope (2.456) than those of the Sri Lankan (2.645), South Indian (3.095), and Turkish (4.072) populations, but more than that of the Jordanian population (1.61). (11) Notably, the slope of the Turkish equation is nearly double that of our equation. (17) Despite both being Mediterranean populations, applying the Turkish equation to our sample would systematically overestimate stature, particularly in individuals with longer ulna. Table 4 illustrates the comparison of male regression equations across other populations.

Table 4. Comparison of male regression equations across other populations

Study	Population	Equation (stature in cm)	r	R^2
Current study	Libyan	107.38 + 2.456 × UL	0.637	0.406
Ilayperuma et al. (2010). (15)	Sri Lankan	97.25 + 2.645 × UL	0.660	0.436
Natarajan et al. (2019). (16)	South Indian	78.06 + 3.095 × UL	0.780	0.608
Paulis et al. (2026). (11)	Jordanian	131.18 + 1.610 × UL	0.522	0.273
Duyar et al. (2005). (17)	Turkish	62.98 + 4.072 × UL	0.775	0.601

UL = ulnar length (cm)

Our R^2 values (females: 0.345; males: 0.406) indicate that ulnar length alone explains approximately one-third to two-fifths of the variance in stature. These values are moderate and are more consistent with those of Natarajan et al. (2019) (R^2 = 0.434). This indicates that other factors such as leg length, spinal height and genetic variability play a significant role in stature in the Libyan population. As expected from known patterns of sexual dimorphism, (16**)** the male slope (2.456) was steeper than the female slope (2.061), suggesting that males possessed longer limbs relative to stature. These moderate associations were similar between men and women, so ulna length can be used to some extent to predict height in both sexes. Our results are comparable to those of Ahmed (2013) who found that ulna length is a good predictor of height in Sudanese people with an accuracy of ±3.54 to 5.85 cm. (18**)** Likewise, Auyeung et al. (2009) found that stature estimation using

the fibula and ulna lengths was as accurate as estimating stature using knee height. They proposed a simple formula involving age, length of the fibula and ulna. Our study confirmed the ulna length as a moderate predictor of height in Libya. It also suggests that different formulae should be used for estimating stature based on sex. (9)

Limitations*:* There were some limitations of this study. First, the sample was restricted to young adult university students (aged 20–25 years) in one Libyan city. The results therefore have a limited generalizability to the Libyan population especially older age groups where stature may decrease due to compression of vertebral discs and postural changes. (19) Other skeletal bone measures (e.g., femur length, knee height, hand dimensions) were not included in this study which could improve the accuracy if included. Stature group specific equations (short, medium and tall) may also improve the accuracy of the regression equation especially if done in a larger sample.

Implications for Forensic Practice: The results indicate that the ulna length measurement could be used to estimate the height of Libyan adults but it would be accurate when using the ulna length with the other long bones such as the femour, tibia and fibula or multiple regression models to estimate the height which may increase the accuracy of the estimates as suggested by Duyar et al. (2006) and Auyeung et al. (2009). (8,16).

Conclusion

The estimation of personal stature from forearm length is an important tool in forensic anthropology and forensic science. It is particularly helpful in situations where full bodies are not found, but partial remains, like forearms. The Libyan model study confirmed that the ulnar length is a reliable predictor of personal height and supported its use in forensic science

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In preparing this AI utilized using Paperpal for language improvement and proofreading. The suggestions generated were critically reviewed, adapted where appropriate, and integrated into my final work. This submission reflects my own understanding and complies with the academic integrity policies of my institution.