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Research Article

Stature Estimation among Iraqis Based on Anthropometrics of the Hands Using Multivariable Regression

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Abstract

Background: Estimating stature is useful in forensics and personal identification. There are no established methods for estimating height among Iraqis in the literature. ***Objective***: To forecast the stature of Iraqis based on the morphometric features of both hands. ***Methods***: We recruited 101 students from Al-Rafidain University College, collected data on ethnicity, gender, weight, and height, and measured fourteen morphometric parameters for each hand, including hand length, palm length, hand breadth, maximum handbreadth, and finger length. To predict stature based on the above variables, the statistician used multivariable linear regression. ***Results***: The sample consisted of males (48.5%) and females (51.5%) aged 18-23 years of Arabic (95%) and Kurdish (5%). We estimated the average weight (65.68±1.32) and height (169.5±21.13). Three prediction equations were developed. The whole sample (accuracy=74.8%, p<0.001) and the male cohort (65%, p<0.001) had significantly higher statistical accuracy than the females (47.2%, p<0.001). Within the overall sample, males assumed commonalities in parameters assigned to both hands, which primarily included the length of the right hand, right middle finger, left palm, and left little finger. Females' stature estimation, on the other hand, correlated to morphometric criteria strictly related to the left hand, such as hand length, palm, ring finger, and little finger. The findings corroborated neural network analysis and qualitative data from the ChatGPT big language model. ***Conclusion***: We successfully developed multivariable prediction models critical to human identification for forensic purposes, such as catastrophic situations caused by disfiguring accidents, organized crime, and mass graves, all of which occurred often in Iraq during the last two decades. Experts in reconstructive hand surgery may be interested in our findings.

Keywords: Anthropometrics of hands, Morphometric studies, Forensic sciences, Arabs of the Middle East, Stature estimation.

تقدير القامة عند العراقيين على أساس القياسات الأنثروبومترية لليدين باستخدام الانحدار متعدد المتغيرات

الخلاصة

الخلفية: تقدير الطول له قيمة استثنائية في علوم تحديد الهوية الشخصية والطب الشرعي. في الوقت نفسه، تفتقر الأدبيات إلى طرق موحدة لتقدير الطول. **الأهداف**: تقدير طول الأفراد العراقيين بناء على المعايير المورفومترية لكلتا اليدين. **الطريقة**: تشمل العينة 101 طالب من كلية الرافدين الجامعة، وتم جمع بيانات تتعلق بالعرق والجنس والوزن والطول، وقياس أربعة عشر معلمة مورفومترية لكل يد، بما في ذلك طول اليد، واتساع اليد، والحد الأقصى لاتساع اليد، وطول كل إصبع. تم استخدام الانحدار الخطي متعدد المتغيرات للتنبؤ بالقامة بناء على المتغيرات السابقة. **النتائج**: شملت العينة الذكور (48.5٪) والإناث (51.5٪) الذين تتراوح أعمارهم بين 18-23 سنة، من العرب (95٪) والأكراد (5٪). تم حساب متوسط الوزن (65.68±1.32) والطول (169.52±1.13). تحليل الانحدار (الدقة = 74.8٪) وتمتلك مجموعة الذكور (65٪) دقة إحصائية أعلى من الإناث (47.2٪). يمتلك تقدير القامة ضمن العينة الكلية والذكور أوجه تشابه فيما يتعلق بالمعلمات المخصصة لكلتا اليدين والتي تضمنت بشكل أساسي طول اليد اليمنى والإصبع الأوسط الأيمن وراحة اليد اليسرى والإصبع الصغير الأيسر. في المقابل، يتوافق تقدير قامة الإناث مع المعلمات المورفومترية المرتبطة ارتباطا وثيقا باليد اليسرى، بما في ذلك طول اليد وراحة اليد والبنصر والإصبع الصغير. تتماشى النتائج أيضا مع تحليلات الشبكة العصبية والبيانات النوعية منchatGPT. **الخلاصة**: تم التنبؤ بالنماذج متعددة المتغيرات التي تعتبر حاسمة في تحديد الهوية الشخصية لأغراض الطب الشرعي عند الكوارث بسبب حوادث التشويه والجريمة المنظمة والمقابر الجماعية التي حدثت بشكل متكرر في العراق خلال العقدين الماضيين. يمكن أن تثير نتائجنا أيضا اهتمام خبراء جراحة اليد الترميمية.

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INTRODUCTION

Stature is the height of the subject (individual) in the upright position. The estimation of stature implies substantial importance in anthropology and forensic disciplines. Therefore, stature estimation methods, relevant statistical accuracy, and reliability must be validated. The four principal cornerstones of forensic anthropometry are predecessors (ancestry), gender, stature, and age of the non-identified person, and these also represent challenges for personal identification for investigators [1]. Measurements and morphometry of the different body parts, such as the ear [2], nose [3], and facial proportions [4], had supreme importance in personal identification. The identification of stature has a crucial role in forensic anthropology and forensic medicine to identify victims or individuals of unknown identities [5]. Personal identification is essential in catastrophic scenarios affecting masses of people, such as mass graves, genocides, and criminal cases of organized crime, among others [6]. On the other hand, there are some limitations and difficulties in predicting the stature of specific individuals because of vertebral column deformities, such as scoliosis, lordosis, and kyphosis; vertebral fractures causing collapses of vertebrae; and pathologies affecting the lower limb due to amputations, contractures, and musculoskeletal deformities, among others [7]. Scientists attempted to estimate the stature of different parts of the body, for instance, based on the morphometry and dimensions of lumbar vertebrae by calculating an inference concerning the correlation between heights and the lengths of different segments of lumbar vertebrae, as in the study by Zhang and coworkers (2015) in the Chinese population [8]. In 2009, Menezes and collaborators suggested estimating the stature of Indian males based on the length of the sternum and its three segments [9]. Other research from Ethiopia and Nigeria explored the possibility of indirectly using the morphometric dimensions of the hand to estimate age and stature [10,11]. In 2011, Kanchan and coauthors studied the morphometry of the hands and feet among individuals from northern India and discussed its benefits for personal identification, especially concerning victims of mass disasters, fatal accidents, and disfiguring assaults [12]. Several studies that researchers conducted among different ethnic groups and geographic locations (Western Australians, Slovaks, Han Chinese, Koreans, and West Bengalis) validated an inference concerning the correlation between stature and various morphometric parameters of the hands and feet while exploring the differential effect of laterality (right versus left) on the accuracy of height predictions [13-17]. Further, Tang *et al*. (2018) implemented simple and multiple linear regression to estimate the stature based on morphometric parameters of the hand among the Han Chinese population [18]. Sen *et al*. (2014) suggested stature estimation based on measuring the length of the ring and index fingers [19]. The former studies and discussion of the literature verified that there are no standardized methods yet to estimate height depending on hand anthropometric dimensions, as they differ based on population socio-demographics, ethnicity, and geographic location. At the same time, there were no relevant studies concerning the estimation of stature for the Iraqi population. The present study aims to explore predictors of stature based on morphometric parameters of the hand and estimate the statistical significance of each among the Iraqi population while using a multivariable model based on linear regression analysis. The ultimate goal is to infer a formula (predictive equation) to predict height with good statistical accuracy among the relevant population. As a secondary objective, the study also aims to calculate standardized values for each morphometric parameter while considering the laterality (right hand versus left hand). The former objective could convey critical information for reconstructive plastic surgeons, orthopedic surgeons, other physicians specializing in hand surgery, and experts in physiotherapy and rehabilitation of hands following traumatic or disabling pathologies. We will also retrieve qualitative data concerning predictors of stature based on large language models (LLM) by accessing the most novel LLM, the Generative Pre-trained Transformer (chatGPT). To the best of the authors' knowledge and per the systematic review of the literature, the current study is the first from Iraq to attempt to create a statistically robust predictive model for estimating stature based on anthropometric parameters of the hands.

METHODS

Ethical considerations and study design

The ethics committee at the department of biotechnology of Al-Rafidain University College approved the study. We also obtained informed consent from each study participant. The current study is cross-sectional and implemented convenience sampling among undergraduate students at Al-Rafidain University College. The researchers collected the data from December 2021 to April 2022. The total sample size represented 101 participants (n=101), including males (n_m=49, 48.5%) and females (n_f=52, 51.5%) aged 19-23 years. The researchers excluded individuals who were disabled or with disfiguring physical injuries.

Morphometry and tools of measurement

The hands of each person were held on a fixed horizontal platform, and the researchers used a standard digital stadiometer to measure the stature (height) and a digital vernier (INGCO HDCD01200 digital vernier caliper) to measure the longitudinal dimensions of interest (morphometric parameters) of the hand. The stadiometer and the vernier were accurate in measurement to the nearest percentile of a millimeter. We measured nine morphometric parameters for each hand (right and left), including hand length (RHL and LHL), palm length (RPL and LPL), handbreadth (RHB and LHB), maximum handbreadth (RMHB and LMHB), and the length of each digit (finger) from the first to the fifth digit (RD1 to RD5 and LD1 to LD5) (Figure 1). Further, the researchers also measured the weight of each subject (participant) using an accurate electronic balance to the nearest percentile of a kilogram.

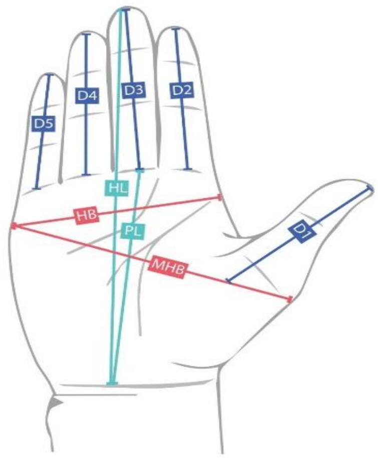

Figure 1: Schematic presentations of the morphometric parameters of the hand.

The systematic review of the databases of literature

The researchers conducted a systematic review of the literature in international and national databases: 1) the PubMed search engine and MEDLINE database of the National Library of Medicine (NLM); 2) the Embase medical literature database from Elsevier; 3) the Iraqi Academic Scientific Journals (IASJ) database; and 4) the University of Baghdad Digital Repository. We browsed the published literature and retrieved articles relevant to the research questions and study aims by combining keywords, medical subject headings (MeSH), and Embase subject headings (Emtree) specific to hand morphometry while using Boolean operators. Later, we scanned through the title, abstract, or full-text manuscript to filter through the search results and include the final list of articles for further secondary analysis.

Qualitative data from large language models

The researchers attempted to retrieve qualitative data concerning the research questions by accessing chatGPT version 3.5, a large language model that OpenAI launched in November 2022. ChatGPT is an AI-powered state-of-the-art search engine and a chatbot that is fine-tuned via reinforcement and supervised machine learning concerning natural language processing. ChatGPT generates a text-based response to a user's query. The chatGPT and other LLMs are powerful, but they also possess certain limitations concerning web queries that may imply harmful content [20].

Data analysis

The raw data were tabulated using Microsoft Excel 2016, and data analyses were conducted using IBM SPSS version 26. We considered an alpha (α) value of 0.05 as the cutoff margin for statistical significance in hypothesis testing. The statistician ran descriptive statistics, Shapiro-Wilk normality testing, bivariate correlation matrices using Spearman's rank-order correlation, independent sample testing using the Mann-Whitney U test, and linear regression analysis. Concerning the regression analysis, the statistician ran a multivariable model (multiple linear regression) while implementing the forward stepwise selection method. Further, the statistician conducted an artificial neural network (ANN) analysis, a modality of supervised machine learning, as a supplementary approach to validate the results from the earlier frequentist statistical methods. Additionally, the statistician performed bootstrapping due to the limited sample size analysis and then used a multilayer perceptron (MLP), implementing the scaled conjugate gradient algorithm and a default allocation of the training and testing to 70% and 30%, respectively.

RESULTS

Patients'attributes and descriptive statistics

The sample included approximately one hundred participants (n=101), aged 18 to 22 years old, including males (n_m=49, 48.5%) and females (n_f=52, 51.5%) of Arabic (n_A=96, 95%) and Kurdish ethnicity (n_K=5, 5%). We calculated the mean and the standard error of the mean for the weight (65.68±1.32), height (169.52±1.13), and each morphometric parameter, including the RHL (18.48±0.13), LHL (18.83±0.15), RPL (100.41±1.03), LPL (99.24±0.96), RHB (83.99±0.77), LHB (82.53±0.87), RMHB (95.79±1.09), LMHB (95.70±1.08), RD1 (57.46±0.50), LD1 (57.43±0.50), RD2 (68.39±0.50), LD2 (68.58±0.50), RD3 (74.70±0.54), LD3 (74.83±0.52), RD4 (70.18±0.52), LD4 (70.40±0.54), RD5 (60.85±0.68), and LD5 (60.82±0.67). We also calculated the same descriptive statistics while stratifying the sample based on gender (Table 1) and implemented the Shapiro-Wilk test to assess the normality of weight, height, and morphometric parameters (Supplementary Materials). Most morphometric parameters did not assume a normal distribution for the total and stratified samples based on gender and ethnicity.

Bivariate correlations

Concerning the bivariate correlations, the correlation matrix conveyed positive and significant correlations between weight, height, and all morphometric parameters at the 99.9% confidence interval (p<0.001). Most of the correlations had moderate-to-large effect sizes. The same applies to correlations between height and morphometric parameters. All correlations were significant and assumed a positive trend. Concerning height, it correlated significantly with: the RHL (Spearman's ρ=0.81, p<0.001), LHL (0.75, p<0.001), RPL (0.59, p<0.001), LPL (0.69, p<0.001), RHB (0.46, p<0.001), LHB (0.64, p<0.001), RMHB (0.37, p<0.001), LMHB (0.33, p<0.001), RD1 (0.40, p<0.001), LD1 (0.39, p<0.001), RD2 (0.55, p<0.001), LD2 (0.56, p<0.001), RD3 (0.67, p<0.001),

Table 1: Descriptive statistics for males and females

Gender	Morphometric Parameter	Mean	
		Statistic	Std. Error
Males	Weight	75.41	1.39
	Height	177.71	1.01
	Right Hand Length	19.39	0.13
	Left Hand Length	19.52	0.11
	Right Palm Length	106.47	0.85
	Left Palm Length	105.88	0.78
	Right Hand Breadth	87.35	0.87
	Left Hand Breadth	87.25	0.85
	Right Maximum Hand Breadth	100.82	1.56
	Left Maximum Hand Breadth	100.62	1.54
	Right Digit#1 Length	60.13	0.60
	Right Digit#2 Length	71.14	0.67
	Right Digit#3 Length	77.99	0.68
	Right Digit#4 Length	72.53	0.62
	Right Digit#5 Length	64.30	0.76
	Left Digit#1 Length	60.00	0.64
	Left Digit#2 Length	71.39	0.66
	Left Digit#3 Length	78.08	0.66
	Left Digit#4 Length	72.61	0.63
	Left Digit#5 Length	64.14	0.76
		Mean	
		Statistic	Std. Error
Females	Weight	56.52	1.24
	Height	161.79	1.25
	Right Hand Length	17.63	0.14
	Left Hand Length	18.18	0.23
	Right Palm Length	94.70	1.43
	Left Palm Length	92.98	1.19
	Right Hand Breadth	80.82	1.07
	Left Hand Breadth	78.08	1.21
	Right Maximum Hand Breadth	91.05	1.20
	Left Maximum Hand Breadth	91.07	1.20
	Right Digit#1 Length	54.94	0.62
	Right Digit#2 Length	65.80	0.54
	Right Digit#3 Length	71.61	0.54
	Right Digit#4 Length	67.97	0.71
	Right Digit#5 Length	57.61	0.90
	Left Digit#1 Length	55.00	0.59
	Left Digit#2 Length	65.93	0.55
	Left Digit#3 Length	71.76	0.52
	Left Digit#4 Length	68.31	0.75
	Left Digit#5 Length	57.70	0.88

LD3 (0.66), RD4 (0.49, $p<0.001$), LD4 (0.42, $p<0.001$), RD5 (0.64, $p<0.001$), and LD5 (0.64, $p<0.001$). We also conducted non-parametric correlations for the stratified sample based on gender. However, these correlations deviated from the total sample, as the correlation matrix indicated that several of the former correlations were insignificant. Still, significant correlations assumed a positive trend, while fewer were significant among the males. Similarly, not all correlations with height were significant, contrary to the total sample.

Multivariable linear regression

Concerning the primary objective, we conducted a multivariable forward stepwise linear regression and excluded the statistical outliers while incorporating height as the dependent (outcome) variable and all other parameters as the independent (predictor) variables. We created three predictive models for the total sample, males, and females (Figure 2). For the total sample, the model was significant and possessed good strength (statistical accuracy=74.8%, $p<0.001$) (Figure 3). The model conveyed seven significant predictors, including RHL (slope coefficient=3.62, $p<0.001$), RD5 (0.415, $p<0.001$), LD4 (-0.50, $p=0.001$), LHL (1.87, $p=0.031$), RD3 (0.36, $p=0.031$), male gender (3.48, $p=0.043$), and Arab ethnicity (4.62, $p=0.094$). All predictors were significant at the 95% confidence interval (95% CI, $\alpha=0.05$) except for ethnicity (significant at 90% CI, $\alpha=0.10$), and each predictor has a positive effect on the outcome (height) except for the length of the left fourth finger (LD4), which possessed an inverse linear relationship with height. Concerning males, the model strength was comparable to that of the total sample (accuracy=65.0%, $p<0.001$). Predictors' importance analysis conveyed almost the same significant predictors for the total sample while excluding gender and ethnicity. The former predictors included: the RHL (5.68, $p<0.001$), LD4 (-0.62, $p=0.002$), RD3 (0.63, $p=0.002$), RD5 (0.25, $p=0.068$), and LPL (-0.21, $p=0.099$). Each predictor influenced height positively except for the length of the left palm and the left fourth finger. Concerning females, the model was less accurate than males and the total sample (47.2%, $p<0.001$), while it conveyed distinct predictors from males and the total sample. The significant predictors of height among females relate strictly to the left hand's morphometry, and these included the LHL (3.90, $p<0.001$), LD4 (-0.63, $p=0.005$), LD5 (0.52, $p=0.013$), and LPL (0.32, $p=0.016$). Contrary to the previous two models, all predictors were significant at 95%, and only one, the length of the left ring (fourth) finger, influenced height negatively (inverse relationship). The linear regression model for the total sample and males has similarities, including good statistical accuracy and overlapping (shared) significant predictors, and each model was statistically robust in predicting heights. In contrast, the third model, for height prediction among females, was weaker (lower statistical accuracy) and possessed somewhat variegated predictors, all of which relate to the left-hand morphometric parameters. Interestingly, each of the three models included the left ring finger (LD4) as a significant predictor of height, which influenced height negatively.

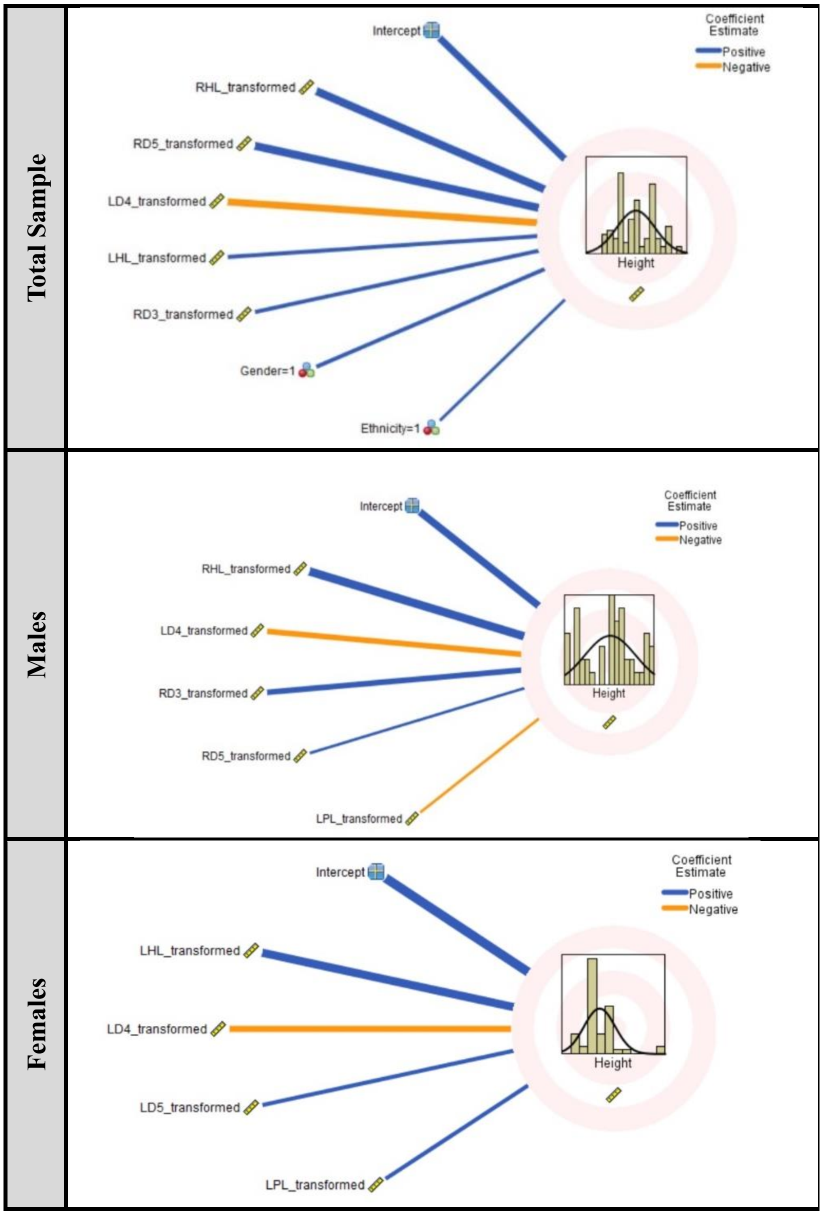

Figure 2: Significant predictors of height per the linear regression analysis.

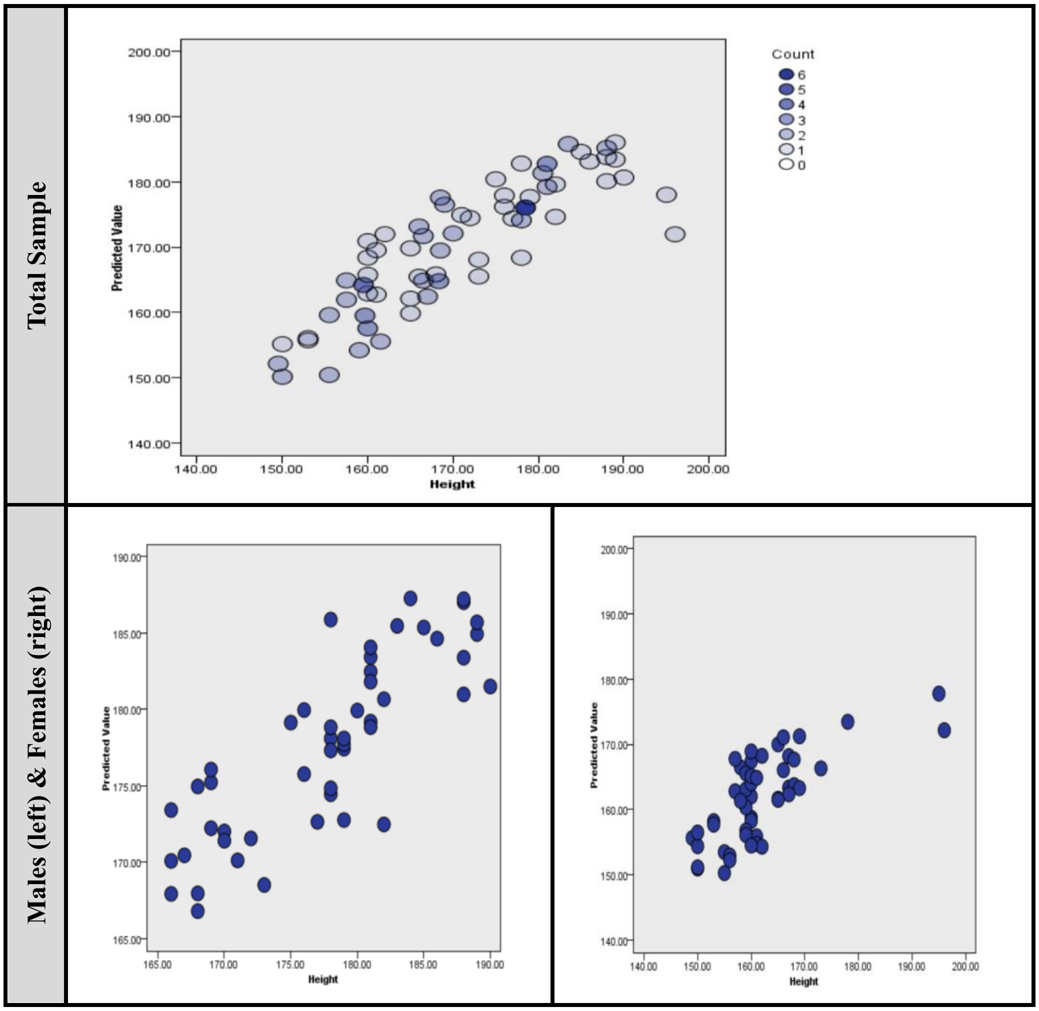

Figure 3: The Observed (x-axis) and predicted value (y-axis) of height for the sample and each gender. † The model's statistical accuracy was 74.8% (total sample), 65% (males), and 47.2% (females).

Table 2: Multivariable regression analysis: Predictive models for height

Sample	Predictive Equation	Accuracy	*p*-value
Total Sample	Height= 44.68 + (3.62 * RHL) + (0.42 * RD5) + (-0.50 * LD4) + (1.87 * LHL) + (0.36 * RD3) + (3.48 * male gender) + (4.62 * Arab ethnicity)	74.8%	<0.001
Males	Height= 69.90 + (5.68 * RHL) + (-0.62 * LD4) + (0.63 * RD3) + (0.25 * RD5) + (-0.21 * LPL)	65.0%	<0.001
Females	Height= 74.71 + (3.90 * LHL) + (-0.63 * LD4) + (0.52 * LD5) + (0.32 * LPL)	47.2%	<0.001

* Left 4th digit (LD4); left 5th digit (LD5); left-hand length (LHL); left palm length (LPL); right 3rd digit (RD3); right 5th digit (RD5); right-hand length (RHL). ** Female gender and Kurdish ethnicity represent the reference category for gender and ethnicity.

Artificial neural networks

We ran the ANN analysis for the total sample, males, and females, to further explore the predictors that the linear modeling labeled as significant at the 95% CI. For the total sample, the independent variables' importance analysis conveyed six predictors: the RHL (importance=0.20, normalized importance=100%), RD5 (0.18, 90.1%), LD4 (0.17, 86.4%), LHL (0.13, 65.1%), RD3 (0.17, 83.4%), and gender (0.16, 81.7%). Concerning males, the MLP's predictors' importance analysis concerned three predictors: the RD3 (0.36, 100%), the LD4 (0.34, 95.3%), and the RHL (301, 85.2%). For females, the importance analysis conveyed four predictors: LPL (0.30, 100%), LD4 (0.30, 99.5%), LHL (0.20, 66.7%), and LD5 (0.19, 64.2%). Further, we ran bivariate correlations concerning the morphometric predictors that we analyzed via the neural networks, and the correlation matrix confirmed the existence of significant bivariate correlations at 99.9% CI

(p<0.001) between each potential pair of these predictors, including RHL, LHL, LPL, RD3, LD4, and LD5. The former correlations assumed a positive linear relationship and possessed moderate-to-large effect sizes (Supplementary Materials). In summary, the results of the multivariable linear regression models were congruent with those from the artificial neural network analyses and the bivariate correlation matrices.

The effect of gender and ethnicity

To complete our analysis, gender-based frequentist statistical testing was conducted using the Mann-Whitney U test concerning all morphometric parameters, including height, right-hand morphometry, and left-hand morphometry. We detected a significant difference concerning all parameters, including those significant predictors that the multivariable linear models generated earlier. All differences were substantially significant (p<0.001), in favor of males and possessed moderate-to-large effect sizes. We also conducted additional tests concerning all parameters for Arabs and Kurds. However, there was only a significant difference in favor of Arabs concerning height (standardized test statistic=-2.01, p=0.044), and conditionally significant differences at 90% CI for LPL (-1.72, p=0.086) and RMHB (-1.75, p=0.081). We conclude that gender and ethnicity significantly affect height, which aligns with the results from the earlier linear regression and neural network models. Nonetheless, the effect of ethnicity on height appeared to be more limited, perhaps due to the small contribution of the Kurds in the current study (Supplementary Materials).

DISCUSSION

Summarization of the results

The current research recruited 101 students, including males (48.5%) and females (51.5%) from Arabic (95%) and Kurdish ethnic backgrounds (5%). The average weight (65.68±1.32) and height (169.52±1.13) were calculated, while significant differences existed concerning height and weight based on gender and hands' morphometry based on laterality (right versus left hand). The bivariate correlations conveyed significant (p<0.001) positive correlations between the hands' morphometric parameters and height and weight. The correlation matrix confirmed significant correlations between each potential pair of right-hand length, left-hand length, left palm length, right middle finger length, left ring finger length, and left little finger length. The former correlations had a positive linear relationship and possessed moderate-to-large effect sizes. The multiple linear regression analysis conveyed higher statistical accuracy for the total sample (74.8%) and the males' cohort (65%) than for females (47.2%). Stature estimation for the total sample and males assumed some shared (similar) predictors allocated to both hands that principally included: right-hand length, right middle finger, left palm length, and left little finger length, in addition to gender and ethnicity. In contrast, stature estimation among females was the least accurate, and the predictors corresponded to morphometric parameters of the left hand only, including the length of the hand, palm, ring finger, and little finger.

Highlights of the most important findings

In summary, the linear predictive model for the total sample and males shared similar features, including good statistical accuracy and some overlapping predictors, and each model was robust in predicting heights. In contrast, the model for height prediction among females was weaker, assumed the lowest statistical accuracy, and possessed somewhat different predictors, all of which relate to left-hand morphometry. We noticed that the three models included the left ring finger (LD4) as a significant predictor of height, yet it influenced height in an inverse (negative) linear relationship. The former results via multivariable linear regression aligned with those from the bivariate correlation matrices and the supervised machine learning via the ANN analyses. Robust multivariable predictive models (formulae) are crucial in personal identification for forensic purposes, such as catastrophic scenarios due to disfiguring accidents, organized crime, and mass graves, which frequently existed in Iraq during the past two decades. The results of the current study concerning hand morphometry could also be necessary for physicians specializing in reconstructive hand surgery.

The systematically-reviewed literature

Relevant studies (from the literature) aligned with our study concerning the importance of using anthropomorphometric parameters of the hands for stature estimation. Further, most of these studies concluded that similar parameters could be used for height prediction. However, a few differences also existed that might relate to racial (ethnic) factors, gender-based differences (sexual dimorphism), the size of the sample and its underlying strata, sampling methods (convenience, random, and stratified random sampling, among others), blinding of researchers who took the measurements, and statistical methods used in these studies, among other factors. Besides, sexual dimorphism and ethnic-based differences could explain the difference in descriptive values, including the average values (mean) and confidence intervals of measurements. On the other hand, the former studies did not implement a multivariable regression analysis; instead, they relied on "limited" univariable linear regression methods. The most relevant study to ours that conveyed comparable results is the one conducted by Pal *et al*. (2014) among 235 undergraduate medical students (n=235) from Eastern India [21]. The former study had a larger sample size than ours. However, they implemented a simple (univariable) linear regression to estimate the height of an individual based on one parameter only, the hand length, without emphasizing the concept of dexterity or lateralization. Nonetheless, Pat and coworkers generated predictive models for stature for both genders with comparable statistical accuracy (Table 2). Concerning females, their model had an almost identical statistical accuracy to ours (48.7% *vs*. 47.2%); however, their model accuracy was inferior to ours concerning the males' cohort (58.3% *vs*. 65%). Pat *et al*.'s study conveyed comparable results to ours, though less accurate for males, while relying on a simplistic (univariable) linear regression model [21]. We opine that our model's superiority relates to implementing several hand morphometric variables (multivariable) to predict stature among Iraqi undergraduate medical students. Besides, our model implemented the forward stepwise selection method to convey superior accuracy compared to traditional multivariable linear regression analysis.

OpenAI ChatGPT large language model

ChatGPT generated a response concerning the predictors of the height query. The LLM confirmed that several factors could predict height in humans, and these include: 1) Genetics: Research has shown that genetic factors account for about 80% of a person's height; 2) Nutrition: Adequate nutrition, especially during childhood and adolescence, is essential for proper growth and development. A lack of certain nutrients, such as protein, can stunt growth. 3) Hormones: Hormones such as growth hormone and thyroid hormone play a role in growth and development. Imbalances or deficiencies in these hormones can affect a person's height. 4) Environmental factors: Environmental factors, such as access to healthcare and living conditions, can also impact a person's height. For example, people exposed to toxins or living in areas with poor air quality may have slower growth rates. 5) Physical activity: Engaging in regular physical activity can help promote growth and development. 6) Age: Height tends to increase until the late teenage years or early twenties, after which it tends to plateau; 7) Gender: On average, men tend to be taller than women. Concerning the predictors of height among Iraqi individuals, they are likely to be similar to those in other populations, as genetics, nutrition, hormones, environmental factors, physical activity, age, and gender all play a role in determining height. However, specific cultural and environmental factors in Iraq could potentially impact these factors and affect the average height of the population. For example, the availability of nutritious food, access to healthcare, and living conditions in Iraq could all potentially impact the growth and development of individuals in the country. It would be interesting to look at data on the average height of Iraqi people and see if there are any notable differences compared to other populations. When it comes to predicting height based on hand morphometric parameters, the web contents' analysis verified that some studies had explored the relationship between hand morphometric parameters (such as hand length, width, and finger length) and height in humans. Some research has found that hand length and width can be used to predict height with a reasonable level of accuracy, particularly in children and adolescents. The accuracy of such predictions may vary depending on the specific population being studied, the methods used, and the age grouping of that population. It is important to note that while hand morphometric parameters may be correlated with height, they are not the only determinants of height and should not be used as the sole basis for predicting height. Factors such as genetics, nutrition, hormones, and environmental factors all play a role in determining height and cannot be accurately assessed based on hand morphometric measurements alone. On the other hand, the large language model could not generate sufficient data concerning height prediction based on the hand's dimensional parameters (morphometry) among Iraqi individuals. Likely, the relationship between hand morphometric parameters and height in Iraqi individuals would be similar to that in other populations, as the factors that influence height (such as genetics, nutrition, hormones, and environmental factors) are likely to be similar across different populations. Further, it is worth noting that the accuracy of predictions based on hand morphometric parameters may vary depending on the specific population being studied and the methods used. In general, hand morphometric parameters may be more helpful in predicting height in children and adolescents, as the relationship between hand size and height tends to be stronger during these stages of development. The relationship between hand dimensions and height may be less robust in adults, and other factors may significantly impact height.

Study Limitations

The current research has constraints, including a limited sample size and the implementation of convenience sampling. The cross-sectional study design also has inherent limitations, such as the capacity to infer the causal relationship between an exposure and an outcome. Nonetheless, the present study does not rely much on causality for "predicting" (estimating) the stature. The researchers also collected data concerning height, ethnicity, and hand morphometry while excluding other parameters of potential importance, such as different age groups, socio-demographics, body mass index (BMI), information on the family history of stature from the maternal and paternal sides, dietary factors and nutritional status, biochemical and hormonal levels, lifestyle, physical activities, history of medical and surgical illnesses, and coexisting pathologies (current history of comorbidities). There could also be biases when measuring the morphometric parameters of the hand. Nevertheless, two researchers recorded each anthropometric parameter for both hands, and when a discrepancy existed, a third measurement was taken, and the final value represented the average value of the measurements. Our results concluded that the multivariable model for predicting females' stature was statistically less accurate than that for males and the total sample. The former gender-based disparity highlighted the presence of alternative predictors of stature estimation among females that may not be limited to hand morphometry, hormonal differences based on gender, and physical activity, among other factors that necessitate surveillance and measurement. Similarly, our sample had limited ethnic diversity. For instance, few Kurds participated in the study, and such representation may not accurately map the underlying Iraqi population strata. Finally, the OpenAI large language model (chatGPT), as its developers programmed it to avoid "toxic" web-based queries, including harmful subjects and racist topics, did not generate relevant or specific data for some queries concerning the ethnic basis of stature estimation. Further, OpenAI explained one of the limitations: "*ChatGPT sometimes writes plausible-sounding but incorrect or nonsensical answers.*". Nevertheless, the authors of the current research did not rely entirely on the large language model. Instead, we used it as an additional source of qualitative data and contrasted the information with the results from our frequentist statistics, multivariable regression analyses, and systematic review of the literature. It is noteworthy to emphasize that chatGPT LLM is still in its "infancy", and it would be interesting to see how it evolves over the following years with interactions with billions of web users and additional training via reinforcement and supervised machine learning.

Conclusions

In the current study, the total sample and males assumed akin features concerning parameters crucial to estimating or predicting height, and they allocated them to both hands, which principally included the length of the right hand, right middle finger, left palm, and left little finger. Contrary to this, stature estimation among females was distinct and corresponded to anthropometrics of the left hand only, including the length of the hand, palm, ring finger, and little finger, while the model for females' height prediction assumed the lowest statistical accuracy. The former findings aligned with auxiliary data from the artificial neural network analysis and the chatGPT large language model. We opine that robust mathematical-based stature estimation models, such as multivariable predictive models, are crucial in personal identification for forensic purposes. The current research successfully created multivariable predictive models for stature estimation that can be pivotal in personal identification by forensic specialists, especially in catastrophic scenarios. Those scenarios are not limited to disfiguring traumatic accidents, including those related to homicide and suicide, organized crime, and mass murders, which, unfortunately, occurred very often in Iraq during the past two decades following the American invasion in 2003. We also highlight that our results could interest experts and physicians specializing in reconstructive hand surgery.

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Conflicts of interest

There are no conflicts of interest.

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Data sharing statement

All data are available upon reasonable request from the corresponding author.

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