ANALYZING SEATED AND STANDING POSTURES WITH ANTHROPOMETRIC MODELING FOR ERGONOMIC DESIGN

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Abstract

The design of workstations and workplaces for ergonomics can be challenging when determining anthropometric parameters such as standing height. This study aimed to develop model equations for determining standing height (SH) using regression analysis as an alternative to measurement. The study involved 406 healthy young adults (206 male and 200 female) aged between 19 and 27years from Abeokuta south western Nigeria. Seated-at-shoulder level (SSL), seated-at-knee level (SKL), popliteal height (PH) and standing height (SH) measurements were taken for each participant. Multivariate regression analyses was used to determine the SH with correlation coefficient (R), coefficient of determination (R^2) and Standard error of estimation (S.E.E) calculated. Study results showed a strong correlation (P<0.00001) between SH and other anthropometric parameters. It was observed that SKL played a more significant role in determining SH with higher values of R and R^2 as well as lower S.E.E in male, female and combined datasets (R: +0.738,+0.578,+0.801), (R^2: 0.544, 0.334, 0.642) and (S.E.E: ±4.192, ±4.007, ±4.115). The study concluded that SKL was a better predictor of SH. This research has significant implications for ergonomics design, forensic science investigation and the determination of SH in the young adult population.

ERGONOMİK TASARIM İÇİN OTURMA VE AYAKTA DURUŞLARIN ANTROPOMETRİK MODELLEME İLE ANALİZİ

Anahtar Kelimeler

Adli
Yükseklik
Genç yetişkinler
İşyeri tasarımı
İş istasyonu tasarımı

Öz

İş istasyonlarının ve işyerlerinin ergonomiye yönelik tasarımı, ayakta durma yüksekliği gibi antropometrik parametrelerin belirlenmesinde zorlayıcı olabilir. Bu çalışma, ölçüme alternatif olarak regresyon analizi kullanılarak ayakta durma yüksekliğinin (SH) belirlenmesine yönelik model denklemlerin geliştirilmesini amaçlamıştır. Çalışmaya Nijerya'nın güneybatısındaki Abeokuta'dan 19 ila 27 yaşları arasındaki 406 sağlıklı genç yetişkin (206 erkek ve 200 kadın) katıldı. Her katılımcı için omuz hizasında oturma seviyesi (SSL), diz hizasında oturma seviyesi (SKL), popliteal yükseklik (PH) ve ayakta durma yüksekliği (SH) ölçümleri alındı. Korelasyon katsayısı (R), belirleme katsayısı (R^2) ve tahminin standart hatası (S.E.E) hesaplanan SH'yi belirlemek için çok değişkenli regresyon analizleri kullanıldı. Çalışma sonuçları SH ile diğer antropometrik parametreler arasında güçlü bir korelasyon (P<0.00001) gösterdi. Erkek, kadın ve kombine veri setlerinde daha yüksek R ve R2 değerleri ve daha düşük S.E.E ile SKL'nin SH'nin belirlenmesinde daha anlamlı rol oynadığı görülmüştür (R: +0.738,+0.578,+0.801), (R^2: 0.544, 0,334, 0,642) ve (GD: ±4,192, ±4,007, ±4,115). Çalışma SKL'nin SH'nin daha iyi bir göstergesi olduğu sonucuna vardı. Bu araştırmanın ergonomi tasarımı, adli tıp araştırmaları ve genç yetişkin nüfusta SH'nin belirlenmesi açısından önemli çıkarımları vardır.

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1. Introduction

Anthropology refers to the measurement of the human body, including its size, shape, and composition. It is used in fields such as ergonomics, physical anthropology, and human factors engineering to study and design environments, products, and systems that are safe and comfortable for people to use. Anthropometric measurements include variables like body weight, height, limb lengths, and circumference measurements of various body parts. These measurements are used to create reference data sets, known as anthropometric databases, that is applicable for designing products and environments that are tailored to the physical characteristics of the user population. Identification of human standing height from anthropometric body parts by mere facial assumption could be very difficult and tasking. But this human standing height is a very important anthropometric parameter useful in the field of medico-legal, healthcare, forensic and also in the ergonomics design of workplace and workstation (Musa et al., 2022a). Human standing height is also a veritable tool in the determination of body mass index of an individual.

Kamal and Yadav (2016) researched into the estimation of standing height from different anthropometric measurement of two hundred participants from Kori population North Indian. The anthropometric parameters measured include knee length, foot breadth, finger length, arm length and head length. The study established regression formula separately to determine the standing height of individual for the kori population (Kamal and Yadav, 2016). Several researchers have equally studied the modeling of anthropometric body parts such as foot length, arm length, leg length to determine standing and body height (Musa et al., 2022a, Musa et al., 2022b, Musa et al., 2022c, Esimonu et al., 2016, Singh et al., 2013).

Singh et al., (2013) performed a study of 226 members of the Gorkha regiment in the Indian Army. Six anthropometric parameters including hand length, foot length, arm length, leg length, standing knee height and standing height were measured by the authors. The output of these measurements determines the standing height of the soldiers through a formulated regression model. Igbigbi et al., (2018) conducted a research into the anthropometric dimension of hand and foot length as predictor of standing height for two different ethnic groups in Nigeria in a study conducted by Yeasmin et al., (2022), the determination of both sex and stature among Bangladeshi adults was examined. The study utilized four (4) body parameters, including knee, popliteal and shoulder designs. heights and shoulder breadth. To establish mathematical model equations for the estimation of standing height, several studies have used different range of statistical method. The most common method used is simple and multiple regressions (Musa et al., 2022b, Yeasmin et al., 2022).

However, only few studies exist as regards ergonomic design of workspace and workstation utilizing anthropometric body parts as an alternative to human standing height. Designs of furniture in our workplace require the human standing height and certainly in our studied population. This is what this study intend to fill. Studies have also showed that anthropometric dimension is population, racial, ethnic, and gender specific (Musa et al., 2022a, Shah et al., 2015, Siqueira et al., 2015). This study will therefore provide a basic and dependable anthropometric data and utilized in the anthropometric studies for the general growth and development of ergonomic design of machine and workplace for conformability. This study might not be a novel but it is need for the design of furniture's, workstation and workplace with the alternative determination of human standing height which is a veritable tool for ergonomic design and body mass index. The study has also added to the pool of knowledge within the field of anthropometric measurements, ergonomic design and forensic investigation.

2. RESEARCH APPROACH

2.1. Sample acquisition

The investigation considered four hundred and six (406) healthy young participants (206 male and 200 female) with no sign of physical deformity or disability were randomly chosen using snowball sampling techniques within Ogun State, South Western, Nigeria. The purposive, judgmental and selective sampling methods were used along with the snowball techniques because it is the best when studying a particular set of groups that have traits that are rare to find due to the insecurity in Nigeria. The study sample consisted of individuals aged 19 to 27years old (male 23.75 ± 2.05 years and 23.34 ± 1.70years). The anthropometric data were collected between the months of September, 2022 to January, 2023.

2.2. Anthropometric measurements

For ergonomics design of workplace and workstation, anthropometric dimension are considered as very important and foundation. The measurements of the anthropometric body dimension were carried out on compliance with ISO 7250. Hence, the measurements of anthropometric are dependent on the method relevant to the

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The Sequence of measurementscomponents, participant's position and equipment used were shown in Table 1 (Pheasant and Haslegrave, 2018).

Table 1. Sequence of Measurements Components, Participant's Position and Equipment Used

Measurement	Participant's position	Equipment
Standing height (SH)	This is a measurement of the subjects head height in Frankfurt position refers to the distance (vertical) from a plane level to the tip of the head.	Stadiometer and Metal measuring tape
Seated-at-Shoulder level (SSL)	This is a distance (vertical) from the surface of the seat to the top (apex) of the shoulder.	Metal measuring tape
Seated-at- knee level (SKL)	This is a distance (vertical) from the foot resting surface (flat surface) to the knee cap with knee flexion at 90^0.	Sliding caliper and Metal measuring tape
Popliteal height (PH)	This measurement represents the vertical distance from the flat surface, where the foot is resting to the posterior surface of the knee when the knee is flexed at a 90 degree angle.	Metal measuring tape

2.3. Analytical Evaluation

The data collected for this study was subjected to analytical evaluation using Statistical Analysis System (SAS) and Microsoft Excel with data analysis tools. The mean, standard deviation, and range of SH, SSL, SKL and PH were computed for male, female and combined datasets. Furthermore, the statistical parameters evaluated in the study included the correlation coefficient (R), coefficient of determination (R^2) and Standard Error of Estimates (S.E.E). This research uses multivariate regression analysis to compute the equation for estimating SH based on measurements of SSL, SKL and PH.

3. RESULT ANALYSIS

Table 2 displays the findings of the descriptive analytical evaluation performed on the anthropometric data gathered in the study.

Table 2. Descriptive Analysis

Gender	Anthropometric dimension	Mean (cm)	S.D (±) cm	Range
Male (n =206)	Age (years)	23.75	2.05	19.00 - 27.00
	SH (cm)	173.00	6.20	161.50 – 187.00
	SSL (cm)	49.37	3.47	42.00 – 60.00
	SKL (cm)	53.73	2.27	50.00 – 59.00
	PH (cm)	47.92	1.46	44.00 – 52.00
Female (n =200)	Age (years)	23.34	1.70	19.00 – 26.00
	SH (cm)	165.02	4.90	153.00 – 172.50
	SSL (cm)	49.18	1.32	47.00 – 51.00
	SKL (cm)	49.07	1.46	51.00 – 52.00
	PH (cm)	39.59	1.98	36.00 – 43.00
Combined (n =406)	Age (years)	23.55	1.90	19.00 – 27.00
	SH (cm)	169.07	6.87	153.00 – 187.00
	SSL (cm)	49.27	2.64	42.00 – 60.00
	SKL (cm)	51.44	3.02	47.00 – 59.00
	PH (cm)	43.82	4.51	36.00 – 52.00

SH – Standing height; SSL – Seated-at-Shoulder level; SKL – Seated-at-knee level; PH – Popliteal height; SD – Standard deviation

Table 2 shows the average values of SH, SSL, SKL and PH for participants as 170.00 ± 6.20cm, 49.37 ± 3.47cm, 53.73 ± 2.22cm and 47.92 ± 1.46cm with the range minimum and maximum values of 161.50 to 187.00cm, 42.00 to 60.00cm, 50.00 to 59.00cm and 44.00 to 52.00cm respectively for male. In the case of female, the average values of SH, SSL, SKL and PH were 165.02 ± 4.90cm, 49.18 ± 1.32cm, 49.07 ± 1.46cm and 39.59 ± 1.98cm with minimum and maximum range of 153.00 to 172.50cm, 47.00 to 51.00cm, 47.00 to 52.00cm and 36.00 to 43.00cm respectively. While combined sex shows that 169.07 ± 6.87cm for SH, 49.27 ± 2.64cm for SSL, 51.44 ± 3.02cm for SKL and 43.82 ± 4.51cm for PH with the range values of 153.00 to 187.00cm, 42.00 to 60.00cm, 47.00 to 59.00cm and 36.00 to 52.00cm for SH, SSL, SKL and PH existed respectively.

Table 3. Regression Formula For Estimating SH (cm)

Gender	Formula	R	R^2	S.E.E	P-value	95%CI	
						lower	upper
Male	130.34 + 0.82*SSL	0.460	0.212	5.518	< 0.000	0.603	1.042
	64.71 + 2.02*SKL	0.738	0.544	4.192	< 0.000	1.761	2.270
	126.24 + 0.98*PH	0.229	0.052	6.050	< 0.000	0.403	1.543
Female	76.45 + 1.80*SSL	0.486	0.236	4.292	< 0.000	1.347	2.255
	70.14 + 1.33*SKL	0.578	0.334	4.007	< 0.000	1.550	2.315
	126.16 + 0.98*PH	0.397	0.157	4.507	< 0.000	0.653	1.300
Combined	120.09 + 0.99*SSL	0.382	0.146	6.357	< 0.000	0.759	1.229
	75.25 + 1.32*SKL	0.801	0.642	4.115	< 0.000	1.691	1.957
	126.95 + 0.96*PH	0.632	0.399	5.333	< 0.000	0.846	1.077

SH – Standing height; SSL – Seated-at-Shoulder level; SKL – Seated-at-knee level; PH – Popliteal height; R^2 – Coefficient of determination; R – Correlation coefficient; S.E.E – Standard Error of Estimation; CI – Confidence of Interval

Table 3 describes the linear regression analysis conducted on anthropometric measurements, specifically exploring the association between SH and other body dimensions such as SSL, SKL, and PH. The study employed a general (simple) linear regression model to assess the relationship between SH and the specified anthropometric measurements. The results indicate a favorable and statistically significant association ($p < 0.0001$) between SH and additional anthropometric measurements, including SSL, SKL, and PH.

Linear regression equations were determined for SH using a single variable in all cases. This implies that the association between SH and each anthropometric measurement was modeled individually. The correlation coefficient (R) values ranged from +0.460 to +0.229 in males, +0.458 to +0.397 in females, and +0.382 to +0.632 in the combined dataset. The values signify both the magnitude and direction of linear correlation between SH and the anthropometric variables. Coefficient of determination (R^2) values ranged from +0.212 to +0.052 in males, +0.236 to +0.151 in females, and +0.146 to +0.399 in the combined dataset. These values represent the proportion of variance in SH explained by the respective anthropometric measurements. Standard Error of Estimation (S.E.E) values were determined and ranged from ± 5.518 to ± 6.052 in males, ± 4.292 to ± 4.507 in females, and ± 6.357 to ± 5.333 in the combined dataset. These values provide an estimate of the average deviation of observed SH values from the regression line. Notably, that S.E.E in males was slightly higher than in females, suggesting that the model's predictions for SH in males may have slightly more variability.

This finding suggests a significant association between SH and other anthropometric measurements. The varied values of correlation coefficients, coefficients of determination, and standard errors provide a nuanced understanding of the strength, direction, and precision of these associations in different datasets and gender groups.

Table 4. Regression Formula for Estimating SH (cm) (Stepwise)

Gender	Formula	p-value	R	R^2	SEE
Male	130.45 + 0.82*SSL	<0.000	0.406	0.212	5.518
	64.71 + 2.02*SKL	<0.000	0.738	0.544	4.195
	70.14 + 1.93*SKL	<0.000	0.578	0.334	4.007
Female	36.35 + 1.52*SKL +1.29*SSL	<0.000	0.637	0.405	3.796
	35.51 + 1.33*SKL +1.041*SSL+0.33*PH	<0.000	0.645	0.419	3.751
	75.25 + 182*SKL	<0.000	0.801	0.642	4.112
Combined	68.37+1.75*SKL + 0.22*SSL	<0.000	0.805	0.649	4.086

SH – Standing height; SSL – Seated-at-Shoulder level; SKL – Seated-at-knee level; PH – Popliteal height; R^2 – Coefficient of determination; R – Correlation coefficient; S.E.E – Standard Error of estimation

Table 4 discusses the application of Multivariate Regression Equations (stepwise) to enhance the

accuracy of determining SH, particularly using SSL, SKL, and PH. The study opted to use Multivariate Regression Equations (stepwise) to determine SH, recognizing the potential for improved accuracy compared to simple linear regression models. The use of Multivariate Regression Equations achieved the intended purpose of higher accuracy in determining SH.

Notably, the study identified a significant accuracy improvement, particularly among the female and combined datasets when using SSL, SKL, and PH as predictors. The results indicate a higher correlation coefficient (R) of 84.5% for females and 80.5% for the combined dataset, highlighting a strong linear relationship between the anthropometric predictors and SH.

The Multivariate Regression models exhibited a slightly lower value of Standard Error of Estimation (S.E.E) of ±3.751cm for females and ±4.086cm for the combined dataset. This suggests that the predictions from the Multivariate Regression models have less average deviation from the observed Sitting Height values, indicating improved precision. The Coefficient of Determination (R^2) values for the Multivariate Regression models were reported as 40.5% and 41.9% for females and 64.9% for the combined dataset. While these values are described as "fair," they still signify a substantial proportion of the variance in SH being explained by the combined predictors.

The application of Multivariate Regression Equations, specifically in a stepwise fashion, appears to enhance the accuracy of Standing Height (SH) determination, especially when considering SSL, SKL, and PH. The higher correlation coefficients and lower Standard Error of Estimation in the female and combined datasets indicate improved predictive performance. Despite the R^2 values being characterized as "fair," they still suggest a significant level of explanation of Standing Height (SH) variability by the selected anthropometric predictors in the Multivariate Regression models

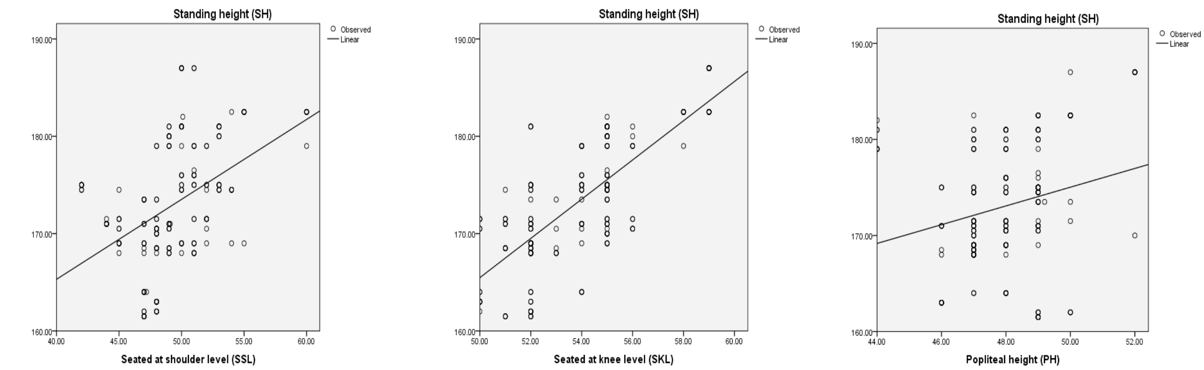

Figure 1. Scatter Plot Graph for Male Participants

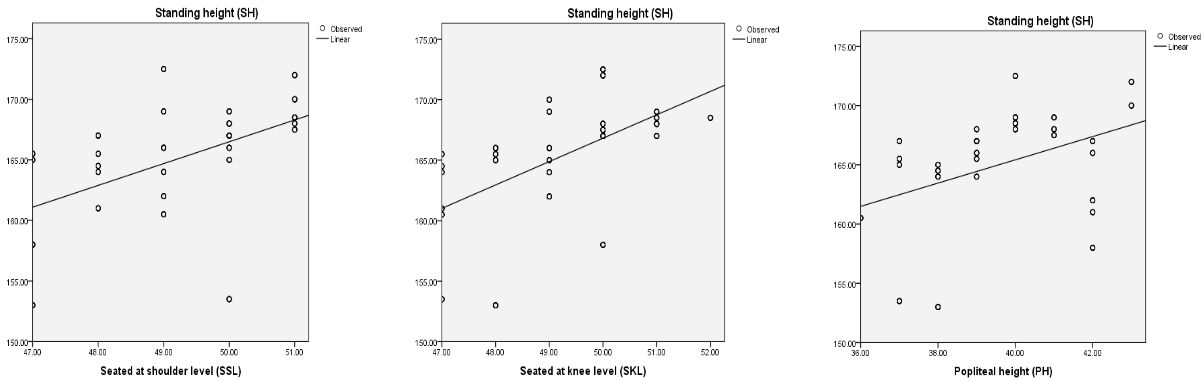

Figure 2. Scatter Plot Graph for Female Participants

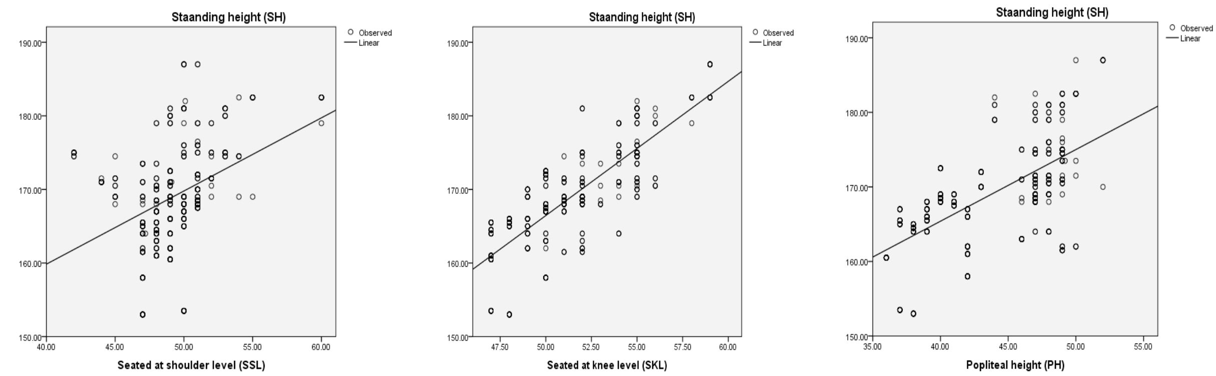

Figure 3. Scatter Plot Graph for Combined Participants

Figure 1, Figure 2 and Figure 3 shows the scatter plot graph of the males, females and combined respondents for the study. A scatter plot visually represents the association between the independent variable(s) and the dependent variable. Reference from the above figures, the plots shows the observed patterns, trends, and potential correlation between the variables. The scatter plot graph (Figure 1, Figure 2 and Figure 3) also identified the outliers, data points that deviate significantly from the overall pattern, are easily noticeable in a scatter plot. Identifying outliers is important because they can strongly influence the regression model and may need special consideration or investigation.

Figure 1, Figure 2 and Figure 3 also shows a linear association between the independent and dependent variables. The scatter plot helps confirm or refute this assumption. If the points form a roughly straight line, it suggests that linear regression may be appropriate. A scatter plot is a fundamental tool in the analysis of linear regression because it helps in assessing assumptions, identifying patterns, and visually communicating the relationship between variables, all of which contribute to the robustness and validity of the regression model.

4. Discussion

The current study uses the anthropometric documentation of SSL, SKL and PH to determine the standing height (SH) of healthy young adults in Abeokuta southwestern Nigeria. The results shows that the anthropometric body dimensions of males were higher than the female counterparts and this difference is due to sexual dimorphism (Bartolomei et al., 2021). Similarly, studies conducted in other population, Singaporean (Chuan et al., 2010), Iranian (Sadeghi et al., 2015), Slovakia (Uhrov´a et al., 2015), Egyptian (Badr et al., 2015), Kori (Kamal and Yadav, 2016), Maldivian (Mohamed et al., 2020) and Bangladeshi (Yeasmin et al., 2022) shows higher anthropometric body dimension in male than female counterpart. Dunsworth (2020) reported that human bone growth depends on estrogen. Thus, this study in Abeokuta south western Nigeria population is consistent with the other findings in other climes.

The current study also exhibited a strong and positive significant correlation between SH and SSL, SKL, PH ($P<0.0001$) respectively. This result indicates that measured SSL, SKL and PH could be very reliable in predicting and determining the standing height (SH) of youngsters' (young adults) in Abeokuta. This result was compared with other population such as Bangladeshi (Yeasmin et al., 2022) and Indonesian (Fatmah, 2009). The findings show that SH is significantly correlated with SSL, SKL and PH in datasets for males, females and both sexes (combined). However, the present study shows that SH are more significantly correlated with SKL (0.738 in male, 0.578 in female and 0.801 in combined). This is in conformity with Nor et al., (2013) that reported correlation of Malaysian population of SH and SKL (0.720 Male and 0.540 Female). Similarly, Maleki and Shariatpanahi (2017) also reported that positive significant correlation existed between SH and SKL in Iranian adult's population. SKL was found to be better predictor in the determination of SH. Increase estrogen production by ovaries leads to the fusion of bones in female bodies before males resulting in sex differences in adult height and mass (Dunsworth, 2020).

According to the results presented in Table 3, the current study found that SKL was the most accurate anthropometric dimension for predicting standing height, as evidenced by its greater values of R, R^2, and lesser S,E.E compared to other dimensions. This finding is in line with previous research conducted on adult Malaysian populations (Nor et al., 2013) as well as a study by Kamal and Yadav (2016) which also found SKL to be the most accurate anthropometric parameter for predicting standing height. Furthermore, the study found that multivariate linear regression models improved accuracy in predicting standing height compared to simple linear regression models, as demonstrated by enhanced values of R, R^2, and decreased S.E.E in both sexes. This finding is consistent with previous research (Ahmed, 2013, Yeasmin et al., 2020).

Several researchers have derived regression model equations to determine the body height, standing height, human height or stature of an individual's of different populations based on various human body parameters (Asadujjaman et al., 2019. Asadujjaman et al., 2020, Mohamed et al., 2020, Yeasmin et al., 2020, Yeasmin et al., 2022, Musa et al., 2022a, Musa et al., 2022b, Musa et al., 2022c). The authors have developed model equations to determine body height utilizing Foot length (Musa et al., 2022a), leg length (Musa et al., 2022b) and Span Arm length (Musa et al., 2022c) Research is still ongoing to further develop model equations from other anthropometric body parameters for workplace design, forensic investigation and medico-legal activities.

5. Conclusion

In summary, this study developed equations for predicting standing height (SH) using anthropometric parameters including SSL, SKL, and PH in young adults from Abeokuta Southwestern Nigeria. The results indicated that SKL was the most significant parameter for predicting standing height, but using multiple linear models with lower estimation error produced more accurate results. This study was the first of its kind in Abeokuta Southwest Nigeria, and could be useful for ergonomists in designing workstations and for forensic experts in identifying unknown human remains. Future research could scrutinize the interrelationship and association between standing height and other health-linked results, such as cardiovascular disease, diabetes, and mortality risk.

Another avenue of exploration could be to investigate the potential applications of the standing height model equations in sports science and athletics, such as predicting performance outcomes or selecting athletes for certain events based on body size and shape. It could also be worthwhile to explore the potential limitations or biases of using anthropometric measurements to predict standing height and body weight, and to consider alternative or complementary methods of measurement.

Future research could also expand upon these findings by incorporating additional anthropometric body parameters such as elbow rest height, bottom popliteal length, hand length, hand breadth, finger length, sitting eye height, and sitting height to improve accuracy in predicting standing height and body weight. Finally, future studies could explore the potential implications of using the standing height model equations developed in this study for the development of more personalized and precise medical treatments and interventions.

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Conflict of interest

Author has no conflicts of interest to disclose.

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