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Development of Gender-Specific Equations for Estimating Body Weight and Height Based on Anthropometric Measurements in Adults from Shiraz, Iran

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Abstract

Background: In various situations, such as determining nutrition requirements, medication dosage, mechanical ventilation, and resuscitation, height, weight, and BMI are considered. Anthropometric body measurements differ among populations of different genders and ethnicities.
Objectives: This study aimed to develop gender-specific equations for estimating body weight and height based on anthropometric measurements in Iranian adults.
Methods: This cross-sectional study was conducted in Shiraz, Iran, over six months. Healthy volunteers aged 18-80 were included. Exclusion criteria were limb(s) amputation or immobilization and pregnancy. Participants were randomly divided into modeling (n = 400) and validation (n = 78) groups. We used the modeling group to generate regression equations based on gender and the validation group to test them.
Results: Demi-span, age, knee height, and arm span could predict height with reasonable accuracy. Calf, waist, neck, and wrist circumferences entered our regression for predicting weight. Waist and calf circumferences entered the regression for BMI prediction in both genders. Arm circumference in men and neck circumference in women is strongly correlated with BMI.
Conclusions: Many different equations have been suggested to predict height, weight, and BMI. Linear and circumferential body measures are usually used to predict height and weight. The suggested equations in this study are simple, and the anthropometric measurements require only a cloth tape measure and have good predictive ability. Complimentary studies are necessary to evaluate the precision of these formulas in other samples from other regions of Iran and in immobilized patients.

Keywords: Body Mass Index, Body Weights and Measures, Body Size, Anthropometry

1. Background

Anthropometric values are closely related to genetics, environmental and social factors. They are used across many scientific disciplines, like evaluation of the prognosis of chronic and acute diseases, risk assessment in different conditions like malnutrition and obesity, studying work-related musculoskeletal disorders, prediction of weight, height, body mass index (BMI), etc. (1-5). In intensive care, we require values like height and weight to calculate various measures. Still, we are not always able to measure them directly. Estimations we make are not precise and can sometimes cause damage (6).

Nutrition therapy in intensive care is a complex process. The ICU team must carefully decide on the route of feeding, the dose of nutrients, and the timing of administration. The dose and proportion of nutrients depend on factors like energy expenditure, routine intensive care interactions with metabolic rate, stress factors, and the patient's body measurements such as weight and ideal body weight. We can employ anthropometry to predict the necessary physical measures (7-10). Medication doses are mainly based on weight; medical teams tend to rely on estimated admission weights that are sometimes unreal (11). Ventilation is another critical part of intensive care and is directly based on the patient's weight. Physicians usually use height to predict their patients' weight, but any errors in their predictions are multiplied when calculating the tidal volume. These errors affect shorter patients more (12). Also, critically ill patients can experience acute muscle wasting, and children rapidly undergo physical changes. Since these measurements are simple, inexpensive, and easy to perform, they can be used for serial measurements in these situations (13, 14).

2. Objectives

Since the anthropometric body measurements may vary in populations of different ages, gender, and ethnicities, the previous models for predicting height, weight, and BMI cannot be generalized to all populations (15). To the best of our knowledge, no studies have been performed to establish predictive models for these parameters in Iranian people. Here, we present models to predict these measures based on anthropometric variables in healthy adult people in Shiraz, southern Iran.

3. Methods

3.1. Study Design and Participants

This is a cross-sectional study conducted in Shiraz, south of Iran. The data were collected over six months, enrolling 516 individuals via convenience sampling. We selected our subjects from individuals who responded to our recruitment flyers that were hung in corridors and waiting rooms of Namazi hospital and Motahhari clinic in Shiraz. The inclusion criteria were healthy adults aged from 18 to 80 years. Volunteers who had limb(s) amputation or immobilization, age < 18, pregnancy, and any chronic illness or medication use were excluded. We randomly divided the individuals who met the criteria (n = 478) into two groups: modeling (n = 400) and validation (n = 78). For equations to be accurate, we separated mentioned groups based on their gender. We used the modeling group for generating the regression equations and the validation group for testing the equations.

3.2. Variable Measurements

Two trained physicians measured and collected demi-span, sitting height, knee height, half span, humeral length, arm span, waist circumference, arm circumference, wrist circumference, and calf circumference with a standard cloth tape measure. Height (centimeters) was measured with a stadiometer. A scale was used for measuring the actual body weight (kilogram). These parameters were recorded with one decimal point. A detailed description of the method and positions for measuring each anthropometric parameter is demonstrated in Table 1.

3.3. Statistical Analysis

We tested the continuous variables between sex groups for normal distribution by visually inspecting the histogram and the Kolmogorov-Smirnov test. The data were reported as mean ± SD and analyzed statically with SPSS for windows version 18 and Microsoft excel 2013.

We used an independent *t*-test to compare all 11 anthropometric parameters between the modeling and validation groups. Then, we used multivariable stepwise linear regression to develop equations in each modeling subgroup (males and females) to identify the relationships between the independent variables and each dependent variable (weight, height, and BMI). A P-value less than 0.05 was considered statistically significant.

To simplify the formulas, we limited the entered variables in each equation by using Akaike's information criterion (AIC) and Bayesian information criterion (BIC) and adjusted R-square (R^2) with each dependent variable (weight, height, and BMI). We performed forward and backward stepwise regression then obtained the original regression equations and modified them to simple formulas with adjusted correlation coefficients and regular constant values.

For external validation, we predicted weight, height, and BMI using the original and simplified formulas and compared the results with the actual measures in the validation group. We calculated the relative error (RE) for each measure by using the following equation:

$$RE = \frac{|\,(predicted\,measure - \,actual\,measure)\,|}{actual\,measure} \quad (1)$$

3.4. Ethics

Participants consented verbally to take part in this study. The institutional review board (IRB) and Shiraz University of Medical Sciences ethics committee approved the study protocol. (Approval Code: IR.SUMS.REC.1398.683)

4. Results

We enrolled 478 individuals in this study. The male-to-female ratio was 2.1:1. The mean age of the participants was 41 ± 25.5 years (ranging from 18 to 80 years). We randomly divided them into modeling (400) and validation (78) groups. There were 269 males and 131 females in the modeling group and 46 males and 32 females in the validation group. There were no significant differences in age

Table 1. Methods of Anthropometric Measurements

Anthropometric Parameter (cm)	Position	Measurement Method
Height	Standing with bare feet	From the vertex of the head to the heel
Demi-span	Supine with shoulder full lateral extension	At the ventral surface from the junction of the deltopectoral groove and anterior axillary fold to the same side
Sitting height	Sitting or supine in a fully erect position	Vertically in the midline from the upper border of the sitting chair to the vertex.
Knee height	Sitting or supine with 90-degree flexion of the knee and neutral ankles	At the lateral aspect, from under the heel to the uppermost point of femur condyles (about 4 cm proximal to (patella)
Half arm span	Supine or sitting	The length between the sternal notch to the tip of the middle finger of the left hand
Arm span	Standing straight against the wall	Length between the tip of the middle finger of the right hand to the tip of the middle finger on the left hand, with both hands straight horizontally at 90° from the body
Humeral length	Supine or sitting with 90-degree elbow flexion	Supine or sitting with 90-degree elbow flexion at the lateral aspect, starting point at the tip of acromioclavicular eminent to the tip of olecranon of the elbow of the non-dominant arm
Waist circumference	In supine position	The narrowest part of the abdominal circumference above the umbilicus
Arm circumference	At supine position	The level at the midpoint between the tip of acromioclavicular eminent to the tip of olecranon of the elbow of the non-dominant arm
Wrist circumference	At sitting position	The narrowest part of the abdominal circumference above the umbilicus
Calf circumference	Sitting or supine	The level at the midpoint between the heel and uppermost point of femur condyles(approximately 4 cm proximal to the patella)
Neck circumference	Supine or sitting	At the level of cricoid cartilage In the anterior and midpoint between external occipital protuberance and the tip of the spinous process

and anthropometric measurements between the modeling and the validation groups. The anthropometric measurements of each group are demonstrated in Table 2. Women were shorter and lighter than men; however, their BMI was comparable to men's. (21.3 ± 3.9 compared to 22.7 ± 3.8 in the modeling group. ($P < 0.001$) (Table 2).

We performed a stepwise linear regression analysis to generate the equations between the actual dependent variables (height, weight, and BMI) and the 12 independent variables. Demi-span, age, and knee height entered our equation for predicting male height (R^2 of 0.68) and Arm span, knee height, and age for women (R^2 of 0.64). Age had an indirect correlation with both genders' height (Table 3).

Table 4 shows the developed equations for predicting weight. The leading variables correlated with men's weight were calf circumference, waist circumference, and neck circumference ($R^2 = 0.85$). Waist, calf, and wrist circumference significantly correlated to women's weight. Age correlated significantly with men's and women's weight ($R^2 = 0.88$) (Table 4).

Table 5 demonstrates Formulas for predicting BMI. Waist and calf circumference were the leading parameters associated with BMI in men and women. Arm circumference and neck circumference were the third parameters to enter the equation for predicting men's and women's BMI, respectively. The overall R square for these equations was 0.92 for both men and women (Table 5).

Table 6 shows the ultimate formulas and their relative errors and R^2 for predicting weight, height, and BMI based on gender. We chose equations with three variables and a considerable predictive ability to simplify the formulas. We confined the coefficient of the equations to simple numbers. The intercepts of equations were also adjusted using the average of covariate values. The adjusted R^2 and relative error were comparable after the validation of the formulas. To test the simplified and original formulas' ability to predict weight, height, and BMI, we applied them to the validation group ($n = 78$) and compared the results with the actual parameters. Correlation, relative error, and mean absolute error were comparable between the original and simplified formulas (All P-values < 0.05). The selected formulas for height had relative errors of 2 - 3.2. The mean absolute error of formulas for estimating weight was 4kg. The predicted BMI in the validation group had a mean error of 0.9 (Table 6).

Table 2. Characteristics of Volunteers in the Model Formulation and the Validation Groups Classified by Sex [a]

Parameters	Female			Male		
	Validation, N = 32 (41%)	Modeling, N = 131 (39.8%)	P-Value	Validation, N = 46 (59%)	Modeling, N = 269 (67.3%)	P-Value
Age (y)	43.7 ± 14.6	41.6 ± 13	0.41	42.1 ± 14.4	40.2 ± 11.5	0.31
Weight (kg)	72.5 ± 12.5	67.2 ± 12.6	0.36	77.3 ± 14.5	79 ± 14.2	0.45
Height (cm)	160.2 ± 7.1	157.9 ± 6.9	0.1	172.8 ± 7.7	173.5 ± 7.9	0.56
BMI (kg/m^2)	22.6 ± 3.7	21.3 ± 3.9	0.87	22.3 ± 3.8	22.7 ± 3.8	0.49
Sitting height (cm)	84.6 ± 6.5	83.8 ± 5.5	0.49	87 ± 10	89.0 ± 7	0.11
Knee height (cm)	46 ± 2.3	45 ± 2.5	0.3	48 ± 3.2	48.1 ± 3.2	0.74
Half span (cm)	82.5 ± 3.6	80.6 ± 4.1	0.18	89.3 ± 4	88.8 ± 5.7	0.54
Demi span (cm)	74.1 ± 3.5	73 ± 4	0.17	81 ± 3.5	80.9 ± 4.1	0.87
waist circumference (cm)	97.9 ± 11.3	94.5 ± 13.4	0.19	96 ± 11.8	95.8 ± 11.4	0.9
Arm circumference (cm)	32.4 ± 3.7	31.1 ± 4	0.98	31.5 ± 3.6	31.3 ± 3.4	0.76
Arm span (cm)	162.4 ± 11.8	161.30 ± 7.9	0.53	178 ± 9	177.6 ± 9.2	0.79
Humeral length (cm)	34.69 ± 2.26	34.00 ± 2.26	0.14	36.14 ± 2.51	36.09 ± 2.53	0.89
Wrist circumference (cm)	16.45 ± 1.25	16.00 ± 1.13	0.6	17.72 ± 1.14	17.7 ± 1.06	0.86
Calf circumference (cm)	39.33 ± 3.86	38.13 ± 3.79	0.11	38.64 ± 4.02	39.13 ± 3.68	0.41
Neck circumference (cm)	34.92 ± 3.13	33.82 ± 2.68	0.63	39.46 ± 2.77	39.21 ± 2.8	0.58

[a] Values are expressed as mean ± SD.

Table 3. Equations for Predicting Height Based on Anthropometric Measures [a]

Model	Male	R	R^2	AIC	BIC	Female	R	R^2	AIC	BIC
1	1.47 (D) + 54.03	0.76	0.58	2102	2114	0.64 (AS) + 52.75	0.75	0.57	1035	1045
2	1.27 (D) -0.19 (A) + 78.27	0.8	0.64	1849	1864	0.52 (AS) + 0.73 (K) + 39.42	0.78	0.61	1008	1021
3	1.06 (D)-0.16 (A) + 0.54 (K) + 67.35	0.82	0.68	1787	1805	0.45 (AS) + 0.84 (K)-0.11 (A) + 50.03	0.80	0.64	968	983
4	0.98 (D)-0.13 (A) + 0.54 (K) + 0.2 (S) + 55.26	0.84	0.70	1723	1745	0.39 (AS) + 0.82 (K)-0.11 (A) + 0.22 (S) + 42	0.81	0.66	928	947
5	0.86 (D)-0.13 (A) + 0.53 (K) + 0.19 (S) + 0.09 (AS)	0.84	0.71	1671	1679	0.3 (AS) + 0.8 (K)-0.1 (A) + 0.25 (S) + 0.56 (H) + 36.32	0.83	0.68	840	960

Abbreviations: AIC, Akaike's information criterion; BIC, Bayesian information criterion; A, age; D, demi span; K, knee height; S, sitting height; AS, arm span; H, humeral length.
[a] All P-values < 0.05; R, correlation coefficient; R^2, adjusted R-square.

Table 4. Equations for Predicting Weight Based on Anthropometric Measures [a]

Model	Male	R	R^2	AIC	BIC	Female	R	R^2	AIC	BIC
1	3.34 (CC) - 51.93	0.86	0.74	2281	2292	0.83 (WC) - 11.91	0.89	0.79	1134	1143
2	2.14 (CC) + 0.54 (WC) - 57.6	0.91	0.83	2094	2113	0.54 (WC) + 1.39 (CC) - 37.56	0.93	0.87	1003	1016
3	1.95 (CC) + 0.37 (WC) + 1.1 (NC) - 76.89	0.92	0.85	1843	1861	0.48 (WC) + 1.16 (CC) + 1.91 (WrC) - 53.49	0.94	0.88	976	992
4	1.56 (CC) + 0.3 (WC) + 0.94 (NC) + 0.84 (AC) - 74.91	0.93	0.86	1810	1832	0.58 (WC) + 1.11 (CC) + 2.01 (WrC) - 0.16 (A) - 56.19	0.95	0.90	944	963
5	1.36 (CC) + 0.4 (WC) + 0.91 (NC) + 0.76 (AC) - 0.12 (A) - 67.7	0.93	0.87	1653	1683	0.53 (WC) + 1.09 (CC) + 1.58 (WrC) - 0.17 (A) - 0.58 (NC) - 63.4	0.95	0.91	794	814

Abbreviations: AIC, Akaike's information criterion; BIC, Bayesian information criterion; CC, calf circumference; WC, waist circumference; NC, neck circumference; AC, arm circumference; A, age; WrC, wrist circumference.
[a] All P-values < 0.05; R, correlation coefficient; R^2, adjusted R-square.

Table 5. Equations for Predicting BMI Based on Anthropometric Measures [a]

Model	Male	R	R^2	AIC	BIC	Female	R	R^2	AIC	BIC
1	0.3 (WC) - 6.75	.92	0.84	1356	1368	0.26 (WC) - 3.69	.92	0.85	670	680
2	0.2 (WC) + 0.42 (CC) - 13.41	.95	0.91	1124	1139	0.18 (WC) + 0.39 (CC) - 11.48	.96	0.91	517	530
3	0.17 (WC) + 0.33 (CC) + 0.2 (AC) - 13.79	.96	0.92	1086	1105	0.16 (WC) + 0.37 (CC) + 0.18 (NC) - 14.72	.96	0.92	420	435
4	0.14 (WC) + 0.32 (CC) + 0.19 (AC) + 0.17 (NC) - 16.98	.96	0.93	959	982	0.14 (WC) + 0.29 (CC) + 0.15 (NC) + 0.15 (AC) - 13.83	.96	0.93	407	425
5	0.14 (WC) + 0.3 (CC) + 0.16 (AC) + 0.16 (NC) + 0.27 (WrC) - 19.45	.96	0.93	946	972	0.15 (WC) + 0.29 (CC) + 0.16 (NC) + 0.16 (AC) - 0.02 (A) - 14.3	.97	0.93	399	420

Abbreviations: AIC, Akaike's information criterion; BIC, Bayesian information criterion CC, calf circumference; WC, waist circumference NC, neck circumference; AC arm circumference; A, Age; WrC, wrist circumference; HL, humeral length; K, knee height.
[a] All P-values < 0.05, R, correlation coefficient R^2, adjusted R-square.

Table 6. Height, Weight, and BMI Predictions and Errors

	Original Formulas [a]	R^2	RE (%)	Error (cm)	Simple Formulas	R^2	RE (%)	Error (cm)
Height								
Male	1.06 (D) - 0.16 (A) + 0.54 (K) + 67.35	0.68	2	3.6 ± 2.8	(D) - (A) /6 + (K) /2 + 75	0.64	2	3.6 ± 2.9
Female	0.45 (AS) + 0.84 (K) - 0.11 (A) + 50.03	0.64	2.2	3.7 ± 2.3	(AS) /2 + 0.8 (K) + (A) /10 + 40	0.64	3.2	4.9 ± 3.5
Weight								
Male	1.95 (CC) + 0.37 (WC) + 1.1 (NC) - 76.89	0.85	4.8	3.8 ± 2.9	2 (CC) + 0.4 (WC) + (NC) - 80	0.88	5.3	4.4 ± 3.0
Female	0.48 (WC) + 1.16 (CC) + 1.91 (WrC) - 53.49	0.88	4.9	4.0 ± 2.8	(WC) /2 + (CC) + 2 (WrC) - 50	0.84	5	4.1 ± 2.5
BMI								
Male	0.17 (WC) + 0.33 (CC) + 0.2 (AC) - 13.79	0.92	4	0.9 ± 0.6	(WC) /5 + (CC) /3 + (AC) /5 - 17	0.93	3.9	0.9 ± 0.6
Female	0.16 (WC) + 0.37 (CC) + 0.18 (NC) - 14.72	0.92	4.2	1 ± 0.7	(WC) /6 + 0.4 (CC) + (NC) /5 - 17	0.93	3.9	0.9 ± 0.6

Abbreviations: A, age; D, demi span; K, knee height; S, sitting height; AS, arm span; H, humeral length; CC, calf circumference; WC, waist circumference NC, neck Circumference; AC arm circumference; WrC, wrist circumference; RE, relative error; error, mean absolute error.
[a] Formulas derived from modeling group, correlation coefficient and error calculated from validation groups.

5. Discussion

We found that Demi span, knee height, and age are predictors for men's height. In women, arm span rather than demi span correlated to height. Our results also showed that measurements of body circumferences such as waist, calf, neck, and wrist could be valid predictors of BMI and weight.

Based on our analysis, demi-span, age, knee height, and arm span could predict height with reasonable accuracy. Previous studies among different populations also show that measuring the linear body parts can be used to estimate height (16-19). A study on Thai adults showed that demi span, sitting height, and knee height are good predictors of height (20). Half span can also be applied for this purpose (16). However, equations based on these body parts must be validated and adjusted for elderly patients (21). Hirani and Mindell reported that demi span could be helpful for height estimation in an elderly population (22). We included age as a variable in our stepwise regression to address the probable impact of age-related vertebral degenerative changes.

Calf, waist, and neck circumferences entered our regression for predicting men's weight. Wrist circumference, instead of neck circumference, was the third variable correlated to women's weight. Research suggests using height and circumferential covariates to predict weight, and some studies have developed formulas. These equations are based on mid-arm, abdominal, and calf circumference (23, 24). Quiroz-Olguin et al. stated that calf, wrist, hip, and waist circumferences are good indices for weight in addition to age and sex (25). Guerra et al. suggest using height and triceps skinfold thickness for weight prediction (26); however, in our study, age and none of the variables correlated to height entered the regression for predicting weight.

Body circumferential measurements seem to have predictive value for BMI too. Waist and calf circumferences entered our regression for BMI prediction in both genders. Arm circumference in men and neck circumference in women strongly correlated with BMI. Based on previous research, waist circumference, neck circumference, waist-stature ratio, and waist-to-hip ratio significantly correlate with BMI (22, 27-30). Arm and demi span can be applied instead of height for BMI estimation in patients whose height cannot be measured accurately (22, 31).

Equations based on anthropometric measurements used to predict weight, height, and BMI, vary among different ages, ethnicities, and genders (32). To develop simple formulas based on the anthropometric characteristic of Iranian people, we analyzed 11 different anthropometric parameters that were previously proven to be reliable for predicting weight and height in other ethnicities. (20, 33-38). We selected the anthropometric indices that only required standard cloth tape for measurement. Also, the coefficients and intercepts of developed equations were adjusted to ordinary numbers to simplify the formulas.

We developed these formulas based on measurements of healthy adults. Further external validation could confirm the applicability of these equations in immobilized diseased patients. Due to random sampling, there was an unequal distribution of men and women in this study. Although we produced different equations for each sex, we might need further validation for women's formulas. Therefore the authors suggest that these formulas should be used only for unavailable data in specific clinical settings.

5.1. Conclusions

Height, weight, and BMI are used to determine nutrition requirements, medication dosage, mechanical ventilation, and resuscitation. In some settings like ICU, it can be challenging to obtain these measures directly. Many different equations have been suggested to predict these parameters. Although linear and circumferential body measures are usually used to predict height and weight, these equations can vary among different ethnicities, genders, and ages. The suggested equations in this study are simple, and the anthropometric measurements require only a cloth tape measure. They have a good predictive ability for estimating adult Iranians' height, weight, and BMI. Complimentary studies are necessary to evaluate the precision of these formulas in other samples from other regions of Iran and the immobilized patients.

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Footnotes

Authors' Contribution: ZS collected the clinical data and helped to draft the manuscript. MA interpreted the clinical data and drafted the manuscript. A.A conceived and designed the evaluation, performed parts of the statistical analysis, and revised the manuscript. KS helped collect the clinical data and revised the manuscript. MH helped collect the clinical data and revised the manuscript. BS interpreted the clinical data and revised the manuscript. NM interpreted the clinical data and revised the manuscript. PG helped to draft the manuscript. MS participated in designing the evaluation and performed the statistical analysis.

Conflict of Interests: The authors declare no competing interests.

Data Reproducibility: The dataset presented in the study is available upon reasonable request from the corresponding author during submission or after its publication.

Ethical Approval: The institutional review board (IRB) and Shiraz University of Medical Sciences ethics committee approved the study protocol (Approval code: IR.SUMS.REC.1398.683; link: ethics.research.ac.ir/ProposalCertificateEn.php?id=76699).

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Informed Consent: Participants consented verbally to take part in this study.

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