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Relationship between Human Body Anthropometric Measurements and Basal Metabolic Rate

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Abstract

Through the use of 3D body measurement technology and cardiopulmonary function test equipment, obtaining the body size data and basal metabolic rate of 116 young healthy subjects, this study aims to find the relationship between the size of human body and basal metabolic rate. Factor analysis, univariate analysis, and linear regression analysis were performed on 13 observed items (selected from 152 human data) by SPSS data analysis software. The 13 observed items include the largest abdominal circumference, waist circumference, chest circumference (horizontal), thigh circumference, hip circumference, weight, total shoulder width, neck circumference, height, waist height, high cervical point, hip height, and chest height. The results indicate that girth and height factors are correlated with the predicted basal metabolic rate as well as the measured basal metabolic rate. The predicted basal metabolic rate is significantly correlated with weight, height, hip circumference, and neck circumference. The measured basal metabolic rate is significantly correlated with the neck circumference as well as height.

Keywords: body measurement, basal metabolic rate, factor analysis, univariate analysis, linear regression analysis

1. Introduction

As the standard of living continues to rise, people are paying more attention to the relationship between their physical beauty and health. The appearance of the human body is a way of self-expression, and people's dissatisfaction with their body size will lead to psychological and physical changes. Study on human body anthropometric measurements is a branch of ergonomics, while the size of human body has a great influence on their physical beauty. In

the medical field, human body anthropometric measurement can be an important indicator for predicating diseases. The study mainly through comparing the correlation between several important human sizes and basal metabolic rate analyzes the anthropometric size with stronger correlation. Through literature searching, it is not difficult to find that many related fields have some research methods and findings that are worth learning and referencing. For example, studies on human sizes and diseases and studies on human physical beauty provide theoretical basis for further experiments to a certain degree.

1.1. Studies on the correlation between anthropometry and physical health

Many studies reveal that the size of the human body not only can indicate the beauty of the human body but also can predict the physiological parameters of the disease [1–3].

In 1996, Seidell et al. found that deaths from cardiovascular disease increased three times in 48, 287 Dutch with body mass index (BMI) greater than 25 kg/m2, indicating that measuring body mass index can, to a certain degree, predict cardiovascular disease [2]. In 2005, Shao et al. eliminated the influence of age and gender on blood glucose metabolism and the interrelationship between several measurement indicators and lipid metabolism indicators through experiments and researches. After that, the study showed that BMI value (anthropometric parameter) has significant positive correlations with fasting blood glucose and true insulin [4]. Meanwhile, neck circumference is also correlated with obstructive sleep apnea-hypopnea syndrome (OSAHS), metabolic syndrome (MS), and hyperandrogenism in women. In the studies of Onat et al., it is found that the correlation between neck circumference and metabolic syndrome is stronger than that between waist circumference and metabolic syndrome. It is also found that the evaluation point of neck circumference to metabolic syndrome is neck circumference >39 cm for men and >35 cm for women and the prediction accuracy can reach 67%. Furthermore, after correcting the components of the metabolic syndrome, neck circumference is still of significance [5]. In 2012, Liang et al. found that waist-height ratio is the best predictor of abnormal glucose metabolism in both men and women. Three thousand and eleven resident subjects over 20 years old were recruited in four cities, by comparing the predictive value of different genders, body mass index, waist circumference, and waist-height ratio for abnormal glucose metabolism [6].

1.2. Studies on the correlation between anthropometry and physical beauty

In terms of studies on physical beauty, people usually evaluate physical beauty based on attractiveness, and human size plays a decisive role in it. In 1986, studies of researchers Hatfield and Sprecher showed that people's attractiveness is attributed to individual qualities and personality [7]. Studies of Buss (1987) and Symons (1995) put forward a basic hypothesis of evolutionary theory of human mate choice, that is, physical beauty is a reliable clue that largely reflects the reproductive potential of women. Such perspective has been extended to many cross-cultural studies. People often evaluate the level of physical beauty of women according to their attractiveness, which is generally divided into nine levels. The first level represents the lowest score, meaning the least attractive and making people feel no sense of physical beauty. The ninth level represents the highest level, meaning the most attractive and

offering the most esthetic sense of physical beauty [8]. In the current correlation studies, the anthropometric parameters that are being widely used to judge attractiveness are waist-hip ratio (WHR), body mass index (BMI), and volume height index (VHI).

In 1993, Devendra Singh, PhD, from the University of Texas, USA, determined that the physical characteristics are sure signs of the reproductive potential of women, while the waist-hip ratio of human, i.e., WHR, is an important indicator. In addition, in the studies of Evans, Barth, and Burke in 1988, WHR was also an accurate predictor of health, and it could be involved in predicting the risk of severe diseases; the lower the ratio, the healthier the individual [9]. During the period from 1830 to 1850, Adolf Quetray, a Belgian scholar, invented body mass index (BMI), to measure fat content with the ratio of height to weight squared (m^2/kg). In the subsequent studies, Tové again verified that BMI is a better indicator to evaluate the physical beauty of women by studying the side and frontal images of women. BMI has been widely used in the medical field. This index was originally used to calculate the fat content of human body, and with the in-depth study on the beauty of human body, it has become an important indicator to evaluate the physical beauty of women. In 2004, Jintu Fan, PhD, from the Hong Kong Polytechnic University proposed a new indicator to evaluate the attractiveness of the 3D image of female body. He noted that volume height index (VHI) is a better indicator than BMI and WHR [10].

1.3. Introduction to basal metabolic rate and its influential factors

Basal metabolic rate refers to the basal metabolic energy consumed by the human body surface area per unit of time, and the unit is generally $kJ \cdot m^{-2} \cdot h^{-1}$ or kJ ($/m^2 \cdot h$) [11]. Basal metabolic rate is of great significance to the studies of human movements, and it can be used to evaluate the status and psychological condition of the human body. As regards medical field, the measurement of basal metabolic rate is a diagnostic method for health; meanwhile, basal metabolic rate is also an important indicator of thyroid disease.

Factors that influence basal metabolic rate are body size, age, gender, hormone, temperature, and surface area [12]. Compared with people who are fat and short, people who are tall and thin have higher basal metabolic rate, which is related to the lean body mass. Normally, the basal metabolic rate of children is higher than that of adults, while that of adults is higher than that of older people. Experiments showed that under the circumstances of same age and same surface area, the basal metabolic rate of men is higher than that of women, that is, because the lean body mass ratio of men is higher than that of women, generally 6–10% higher. And 10–15% higher is within the normal range. The basal metabolic rate of pregnant women is evidently increased, which is related to the increase in calories burned in the body. Furthermore, hormones also have a great impact on basal metabolic rate, and the secretion of hormones can regulate cell metabolism. For instance, hyperthyroidism will increase the basal metabolic rate, and when suffering from myxedema, the basal metabolic rate will decrease significantly [12]. Differences in seasons can also lead to differences in basal metabolic rates. Usually, the basal metabolic rate in winter is higher than that in summer. The basal metabolic rate is basically proportional to the body surface area and out of proportion to weight [11]. Therefore, body surface area is a standard to measure metabolic rate.

1.4. Calculation method of basal metabolic rate

In 1894, Rubner argued that the basal metabolic rate is relatively constant when represented by per body surface area, which is significantly associated with body weight and height [13]. Harris-Benedict established the initial equation of basal metabolic rate in 1919 [14]:

Male: $P = 13.7516 \, m/1 \, kg + 5.0033 \, h/1 \, cm^{-6} \times 7550a/1 \, year + 66.473$

Female: $P = 9.5634 \, m/1 \, kg + 1.8496 \, h/1 \, cm^{-4} \times 6756a/1 \, year + 655.0955$

In the equation, P represents the total body heat production in the state of rest, and its unit is kcal/day; m is the weight, and its unit is kg; h is the height, and its unit is cm; a is the age, and its unit is year. However, the maximum value of energy consumption calculated by such classic equation is hugely different from that calculated by the domestic calculation method in Chia (same gender, height, weight, and age), with the former significantly higher than the latter [15]. In 1928, Paul H. Stevenson published the findings of body surface area of Chinese in the Chinese Journal of Physiology [16]. With changes in the body of the Chinese people, their weight and height have also changed obviously. Songshan Zhao further explored the body of Chinese in 1983, and progress has been made in the correlation among human body surface area, weight, and height [16]. And the formula that can reasonably reflect the body surface area of adults in China so far has been obtained:

$A = 0.00659H + 0.0126 \, W - 0.1603$ [16]

A represents the body surface area (m^2), H the height (cm), and M the weight (kg).

2. Methodology

2.1. Subjects

About 116 young healthy men and women at 18–26 years old were invited to participate in the study, embodying 95 females and 21 males. Through the relevant literature, we selected 13 human data as observations. **Table 1** shows the 13 basic dimensions and body mass index (BMI) of the 116 subjects, while **Table 2** demonstrates the experimental data on metabolic rate of 116 subjects.

2.2. Testing equipments

Voxelan (Hamano Engineering Co. Ltd. Japan) 8CCD 3D scanner obtained regional images through a camera and obtained relevant body data by converting the images into spatial points with a model software. Anthroscan (Scanworx) 3D image data processing software was used to purify, smooth, and triangular mesh reconstruct the scanning images to generate closed human body automatically, to extract human body size precisely and measure the size of human body interactively, including distance, circumference and angle. Therefore, it can extract the section image of the human body and analyze it arbitrarily. MetaMax 3B sports cardiopulmonary telemetry tester, a series of German CORTEX product, can collect

Testing items	Max	Min	Mean
Body height (cm)	176.0	152.0	162.2
Weight (kg)	82.2	40.3	54.6
Bust girth (horizontal) (cm)	119.0	78.0	87.9
Waist girth (cm)	115.9	60.5	71.7
Buttock girth (cm)	118.1	81.1	92.8
Maximum belly circumference (cm)	123.3	64.9	79.2
Mid-neck girth (cm)	38.6	28.3	32.8
Thigh girth (right) (cm)	64.5	43.8	52.3
Across shoulder (cm)	49.3	37.0	41.8
Bust height (cm)	128.4	102.2	117.0
Waist height (cm)	109.8	87.5	101.0
Neck height (cm)	150.8	122.1	138.2
Buttock height (cm)	89.2	69.4	80.5
BMI (kg/m^2)	30.2	16.2	20.2

Table 1. Body size and BMI index of 116 subjects.

Parameter	Max	Min	Means
Oxygen uptake (L/min)	0.326	0.127	0.228
Carbon dioxide output (L/min)	0.269	0.107	0.191
Respiratory quotient (%)	1.070	0.62	0.838
Heart rate (bpm)	111.000	57.000	77.731
Measured basal metabolic rate (%)	2260.000	902.000	1595.999
Predicted basal metabolic rate (%)	2070.000	1359.000	1549.148
Lipid oxidation rate (%)	84.000	0.000	43.426

**Table 2.** Experimental data on metabolic rate of 116 subjects.

gas metabolism parameters during exercising and breathing, such as VO2, VCO2, respiratory rate, heart rate, respiratory exchange rate, ventilation volume, and environmental temperature and atmospheric pressure.

2.3. Experimental protocol

This experiment was conducted in an artificial climate chamber (temperature, 25 ± 2°C; humidity, 50 ± 2%). All subjects were required to wear sportswear, of whom the female shall

put on the special underwear with gym short while the male shall wear the sport short only. Before starting the experiment, subjects were expected to fill in the basic personal information, such as age, gender, weight, and so on. When taking 3D body scanning, the subjects erectly stood on the scanner platform and spread feet 15 cm with arms lifting outward and smooth breathing. Scanning will be completed within 5–10 s. After that the body fat composition of the subjects would be measured. Besides, while taking the metabolic test, subjects sat in a quiet room with physical relaxation. The testing time varies from person to person, and about 15 min is required for most subjects.

After scanning with Voxelan 3D laser scanner, Anthroscan (Scanworx) 3D image data processing software was used for obtaining statistical data, importing the scanned.obj cloud point map into Anthroscan, reducing the scale by 1:500 and adjusting X, Y, and Z axes. Therefore, the human body was facing the right side for intelligent repair. After obtaining the complete human body models, human body anthropometric measurements were carried out. Such data and the data of metabolic measurements were imported into the Excel spreadsheet. Spss19.0 was finally used to analyze the data correlation. The images of part of the subjects that were scanned by the 3D scanner and processed by the Anthroscan (Scanworx) 3D image software are shown in **Figures 1** and **2**.
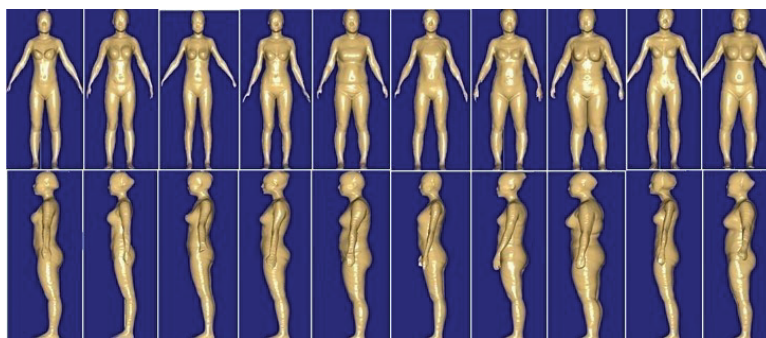
Figure 1. Part of 3D scanning images of female subjects.
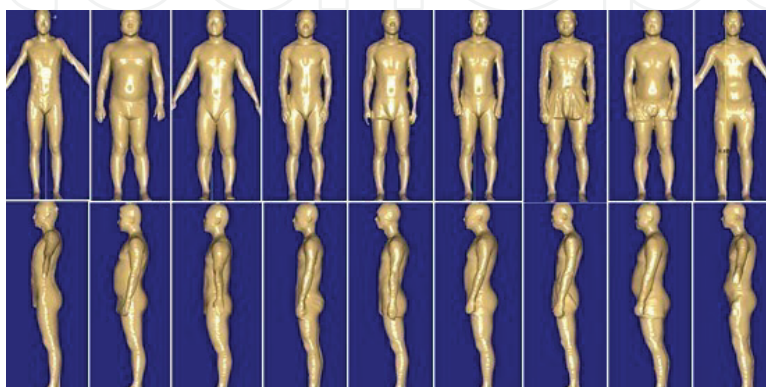
Figure 2. Part of 3D scanning images of male subjects.

3. Results and discussion

3.1. Factors

Factor analysis was carried out to analyze the maximum abdominal circumference, waist circumference, chest circumference (horizontal), right thigh circumference, hip circumference, weight, total shoulder width, mid-neck girth, height, waist height, cervical height, hip height, and chest height, so as to verify if the data were appropriate for correlation analysis.

The KMO value is greater than 0.05 and close to 1, sig. = 0.000 < 0.05, so the 13 observed items are suitable for factor analysis (**Table 3**). After preliminary analysis, it was found that the basal metabolic rate was not significantly related to gender, and therefore, 13 representative sizes of the subjects were analyzed. For **Table 4** reveals high communality of each factor, the extracted components can be well described by these variables. Meanwhile, in the light of **Table 5**, the eigenvalues of the first two factors are 6.985 and 3.833, respectively, accounting for 83.596% of the total variance. The first two factors explain the variance of 83.596% of the original 13 factors; hence, we will confirm to extract the two principal components.

In order to name these factors, we rotated the factors so that the coefficients were polarized to 0 and 1. By rotating the factor matrix, the factor can be named and interpreted (**Table 6**). Factor 1 is named the girth factor since it can represent waist girth, maximum belly circumference, bust girth (horizontal), thigh girth (right), buttock girth, weight, across shoulder, and mid-neck girth. Factor 2 is named the height factor as it can represent waist height, neck height, bust height, buttock height, and body height. The coefficient of principal component score is shown in **Table 7**.

Standardized first factor = 0.178 × maximum belly circumference + 0.171 × waist girth + 0.171 × bust girth (horizontal) + 0.166 × thigh girth (right) + 0.154 × buttock girth + 0.135 × weight + 0.112 × across shoulder + 0.104 × mid-neck girth − 0.017 × body height − 0.043 × waist height − 0.022 × neck height − 0.044 × buttock height − 0.037 × bust height.

Standardized second factor = −0.066 × maximum belly circumference − 0.036 × waist girth − 0.047 × bust girth (horizontal) − 0.059 × thigh girth (right) − 0.015 × buttock girth + 0.047 × weight + 0.023 × across shoulder + 0.051 × mid-neck girth + 0.189 × body height + 0.203 × waist height + 0.196 × neck height + 0.198 × buttock height + 0.200 × bust height.

3.2. Factors and predicted basal metabolic rate

According to **Figure 3**, the girth and height are highly related to the predicted basal metabolic rate with linear correlation. The correlation coefficients between predicted basal

Kaiser-Meyer-Olkin measure of sampling adequacy		0.843
Bartlett's test of sphericity	Approx. Chi-Square	2403.025
	df	78.000
	Sig.	0.000

Table 3. Kmo and Bartlett's test.

	Initial	Extraction
Maximum belly circumference	1.000	0.849
Waist girth	1.000	0.867
Bust girth (horizontal)	1.000	0.830
Thigh girth (right)	1.000	0.750
Buttock girth	1.000	0.768
Weight	1.000	0.919
Across shoulder	1.000	0.544
Mid-neck girth	1.000	0.629
Body height	1.000	0.930
Waist height	1.000	0.954
Neck height	1.000	0.974
Buttock height	1.000	0.901
Bust height	1.000	0.952

Table 4. Communalities.

Factor	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	6.985	53.729	53.729	6.985	53.729	53.729	5.741	44.165	44.165
2	3.883	29.867	83.596	3.883	29.867	83.596	5.126	39.431	83.596
3	0.853	6.560	90.156						
4	0.383	2.948	93.103						
5	0.247	1.899	95.003						
6	0.214	1.650	96.652						
7	0.135	1.040	97.693						
8	0.111	0.855	98.548						
9	0.067	0.517	99.065						
10	0.051	0.390	99.455						
11	0.041	0.315	99.770						
12	0.018	0.140	99.910						
13	0.012	0.090	100.000						

Table 5. Analysis on all variances.

	Component	
	1	**2**
Waist girth	0.928	0.077
Maximum belly circumference	0.919	−0.070
Bust girth (horizontal)	0.911	0.017
Thigh girth (right)	0.865	−0.049
Buttock girth	0.862	0.156
Weight	0.848	0.448
Across shoulder	0.679	0.287
Mid-neck girth	0.674	0.418
Waist height	0.062	0.975
Neck height	0.171	0.972
Bust height	0.094	0.971
Buttock height	0.051	0.948
Body height	0.192	0.945

Table 6. Rotation component matrix.

	Component	
	1	**2**
Maximum belly circumference	0.178	−0.066
Waist girth	0.171	−0.036
Bust girth (horizontal)	0.171	−0.047
Thigh girth (right)	0.166	−0.059
Buttock girth	0.154	−0.015
Weight	0.135	0.047
Across shoulder	0.112	0.023
Mid-neck girth	0.104	0.051
Body height	−0.017	0.189
Waist height	−0.043	0.203
Neck height	−0.022	0.196
Buttock height	−0.044	0.198
Bust height	−0.037	0.200

Table 7. Component score coefficient matrix.
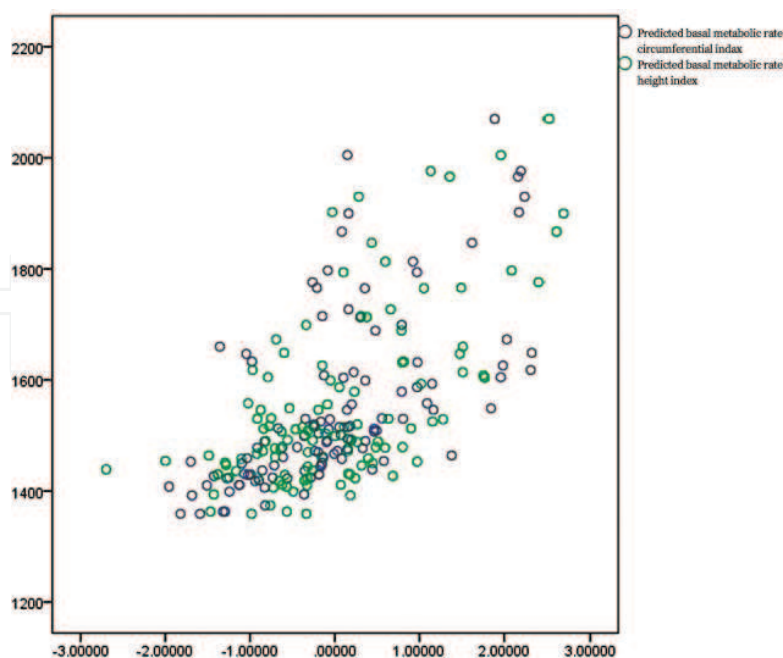
Figure 3. Simple scatterplot of factors and predicted basal metabolic rate.

metabolic rate and girth index and predicted basal metabolic rate and height index are 0.627 (sig. = 0.000 < 0.01, reject null hypothesis) and 0.634 (sig. = 0.000 < 0.01, reject null hypothesis), respectively. The results unveil that there is a significant correlation between predicted basal metabolic rate and girth index and predicted basal metabolic rate and height index, respectively (**Table 8**).

Table 9 [(a) predicator variable, height index; (b) predicator variable, height index and circumference index; (c) dependent index, predicted basal metabolic rate] lists the sources of variation, degree of freedom, mean squares, F value, and the significant test of F. The mean squares among group two models are far greater than that within the group. The statistical value of F is 216.155, sig. <0.05, so the regression equation established is valid.

According to **Table 10**, in model 2, dependent variable Y regression on the two independent variables X1 and X2 of the nonstandardized regression coefficients are 98.698 and 97.650, respectively, while T values of the corresponding saliency detection are 14.780 and 14.624, respectively, and the significant level of their regression coefficient (sig.) is 0.000, which is less than 0.05. Hence, it can be deduced that there is a definite linear relationship between the two factors and measured basal metabolic rate.

3.3. Factors and measured basal metabolic rate

The correlation between the weight index, height index, and predicted basal metabolic rate was analyzed. It can be observed from the scatterplot in **Figure 4** that there is a correlation between weight index, height index, and predicated basal metabolic rate, and the linear trend of the scatterplot is not obvious.

		Predicted basal metabolic rate	Circumferential index	Height index
Predicted basal metabolic rate	Pearson's correlation coefficient	1	0.627**	0.634**
	Sig. (two-sided)		0.000	0.000
	N	114	114	114
Circumferential index	Pearson's correlation coefficient	0.627**	1	0.000
	Sig. (two-sided)	0.000		1.000
	N	114	114	114
Height index	Pearson's correlation coefficient	0.634**	0.000	1
	Sig. (two-sided)	0.000	1.000	
	N	114	114	114

Table 8. Correlation analysis between two factors and predicted basal metabolic rate.

Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	1100764.555	1	1100764.555	75.320	0.000[a]
	Residual	1636821.445	112	14614.477		
	Total	2737586.000	113			
2	Regression	2178287.472	2	1089143.736	216.155	0.000[b]
	Residual	559298.528	111	5038.725		
	Total	2737586.000	113			

[a]Predictor variables: height indicator.
[b]Predictor variables: height indicator and girth indicator.
[c]Dependent variable: predicted basal metabolic rate.

Table 9. Anova.

Coefficients[a]

Model		Nonstandardized coefficients		Standardized coefficients	T	Sig.
		B	Std. error	Beta		
1	(Constant)	1551.000	11.322		136.985	0.000
	Height index	98.698	11.372	0.634	8.679	0.000
2	(Constant)	1551.000	6.648		233.294	0.000
	Height index	98.698	6.678	0.634	14.780	0.000
	Girth index	97.650	6.678	0.627	14.624	0.000

[a]Dependent variable: predicted basal metabolic rate.

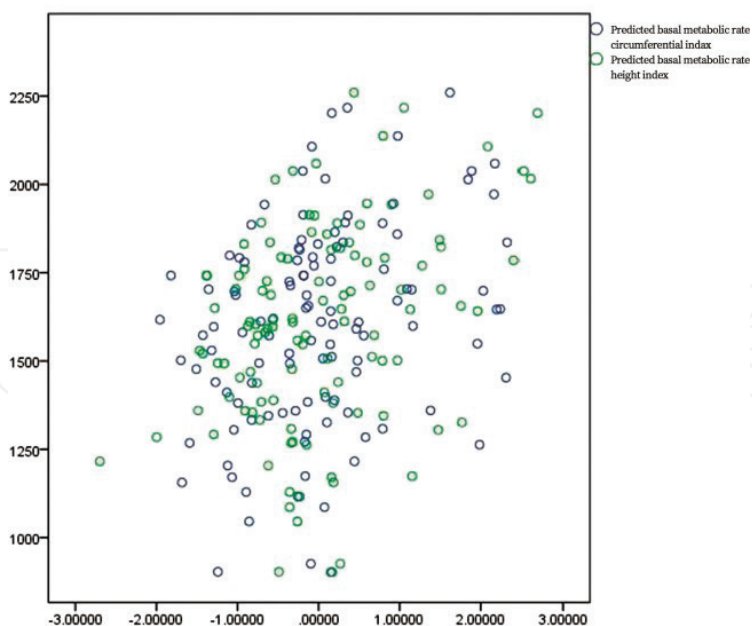**Table 10.** Regression coefficient.

Figure 4. Simple scatterplot of factors and measured basal metabolic rate.

		Measured basal metabolic rate	Circumferential index	Height index
Measured basal metabolic rate	Pearson's correlation coefficient	1	0.303**	0.349**
	Sig. (two-sided)		0.001	0.000
	N	114	114	114
Circumferential index	Pearson's correlation coefficient	0.303**	1	0.000
	Sig. (two-sided)	0.001		1.000
	N	114	114	114
Height index	Pearson's correlation coefficient	0.349**	0.000	1
	Sig. (two-sided)	0.000	1.000	
	N	114	114	114

Table 11. Correlation analysis between two factors and measured basal metabolic rate.

The consequence indicates that the correlation coefficient between the measured basal metabolic rate and the height index, the measured basal metabolic rate, and the girth index are 0.303 (sig. = 0.001 < 0.01, reject null hypothesis) and 0.349 (sig. = 0.000 < 0.01, reject null hypothesis), respectively. Accordingly, we can conclude there is an insignificant correlation between the measured basal metabolic rate and the height index, measured basal metabolic rate, and the girth index, respectively (**Table 11**).

3.4. Univariate and predicted basal metabolic rate

Select the maximum abdominal circumference, waist circumference (horizontal), chest circumference, mid-neck girth, right thigh circumference, hip circumference, weight, total shoulder width, and height as independent variables, and select the predicted basal metabolic rate as dependent variable, and then regression analysis was performed.

According to **Table 12**, except for the right thigh variable, weight, height, hip circumference, and neck circumference variables are embedded into regression model.

Besides, there is high R square value on model 1, 2, 3, 4, 5, and 6, which unveils the dependent and independent variables are highly correlated (**Table 13**).

The F value in model 6 is 358.808, and sig in all models is 0.000, less than 0.01, which has a strong significance. Meanwhile, all the regression variances are greater than residuals, indicating the established regression equation is effective (**Table 14**).

It can be observed from **Table 15** that the multivariate regression equation should be F = 56.615 + 15.131 × weight + 6.504 × height − 8.266 × hip circumference + 11.180 × mid-neck girth. However, because the sig. Value of the constant value is 0.772 > 0.1, the constant value is not significant. Therefore, there is no data in the column of constant value, which has been removed. So the standardized equation is Y = 0.771 × weight + 0.268 × height − 0.243 × hip circumference + 0.197 × mid-neck girth.

3.5. Univariate and measured basal metabolic rate

A linear regression analysis was performed on the nine independent variables and the dependent variable-basal metabolic rate. The nine independent variables are the maximum abdominal circumference, waist circumference (horizontal), chest circumference, mid-neck girth, right thigh circumference, hip circumference, weight, total shoulder width, and height.

Variables entered/removed[a]

Mode	Variables entered	Variables removed	Method
1	Weight	—	Stepwise (criteria: probability-of-F-to-enter ≤ 0.005, probability-of-F-to-enter ≥ 0.100)
2	Thigh girth (right)	—	Stepwise (criteria: probability-of-F-to-enter ≤ 0.005, probability-of-F-to-enter ≥ 0.100)
3	Body height	—	Stepwise (criteria: probability-of-F-to-enter ≤ 0.005, probability-of-F-to-enter ≥ 0.100)
4	Buttock girth	—	Stepwise (criteria: probability-of-F-to-enter ≤ 0.005, probability-of-F-to-enter ≥ 0.100)
5	Mid-neck girth	—	Stepwise (criteria: probability-of-F-to-enter ≤ 0.005, probability-of-F-to-enter ≥ 0.100)
6	—	Thigh girth (right)	Stepwise (criteria: probability-of-F-to-enter ≤ 0.005, probability-of-F-to-enter ≥ 0.100)

Table 12. Modeling.

Model	R	R square	Adjusted R square	Std. error of the estimate
1	0.898[a]	0.806	0.804	68.926
2	0.943[b]	0.890	0.888	52.127
3	0.952[c]	0.906	0.904	48.245
4	0.959[d]	0.919	0.917	44.965
5	0.964[e]	0.930	0.927	42.170
6	0.964[f]	0.929	0.927	42.104

[a]Predictive variable: (constant), weight.
[b]Predictive variable: (constant), weight, thigh girth (right).
[c]Predictive variable: (constant), weight, thigh girth (right), body height.
[d]Predictive variable: (constant), weight, thigh girth (right), body height, buttock girth.
[e]Predictive variable: (constant), weight, thigh girth (right), body height, buttock girth, mid-neck girth.
[f]Predictive variable: (constant), weight, body height, buttock girth, mid-neck girth.
[g]Dependent variable: predicted basal metabolic rate.

Table 13. Model summary[a].

Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	2205499.952	1	2205499.952	464.241	0.000[a]
	Residual	532086.048	112	4750.768		
	Total	2737586.000	113			
2	Regression	2435975.842	2	1217987.921	448.250	0.000[b]
	Residual	301610.158	111	2717.209		
	Total	2737586.000	113			
3	Regression	2481549.406	3	827183.135	355.379	0.000[c]
	Residual	256036.594	110	2327.605		
	Total	2737586.000	113			
4	Regression	2517200.603	4	629300.151	311.244	0.000[d]
	Residual	220385.397	109	2021.884		
	Total	2737586.000	113			
5	Regression	2545528.093	5	509105.619	286.286	0.000[e]
	Residual	192057.907	108	1778.314		
	Total	2737586.000	113			

Model		Sum of squares	df	Mean square	F	Sig.
6	Regression	2544352.653	4	636088.163	358.808	0.000[f]
	Residual	193233.347	109	1772.783		
	Total	2737586.000	113			

[a]Predictor variables: (constant), weight.
[b]Predictor variables: (constant), weight, thigh girth (right).
[c]Predictor variables: (constant), weight, thigh girth (right), body height.
[d]Predictor variables: (constant), weight, thigh girth (right), body height, buttock girth.
[e]Predictor variables: (constant), weight, thigh girth (right), body height, buttock girth, mid-neck girth.
[f]Predictor variables: (constant), weight, body height, buttock girth, mid-neck girth.
[g]Dependent variable: predicted basal metabolic rate.

Table 14. Anova.

		Nonstandardized coefficients		Standardized coefficients	t	Sig.
Coefficients[a]						
Model		B	Std. error	Beta		
1	(Constant)	591.996	44.975		13.163	0.000
	Weight	17.615	0.818	0.898	21.546	0.000
2	(Constant)	1164.971	70.904		16.430	0.000
	Weight	23.644	0.900	1.205	26.258	0.000
	Thigh girth (right)	−17.221	1.870	−0.423	−9.210	0.000
3	(Constant)	297.992	206.631		1.442	0.152
	Weight	19.243	1.298	0.981	14.829	0.000
	Thigh girth (right)	−11.486	2.162	−0.282	−5.313	0.000
	Body height	4.909	1.109	0.202	4.425	0.000
4	(Constant)	588.554	204.637		2.876	0.005
	Weight	20.533	1.248	1.046	16.455	0.000
	Thigh girth (right)	−5.100	2.525	−0.125	−2.020	0.046
	Body height	5.343	1.039	0.220	5.141	0.000
	Buttock girth	−8.278	1.971	−0.243	−4.199	0.000
5	(Constant)	142.712	222.059		0.643	0.522
	Weight	15.874	1.653	0.809	9.603	0.000
	Thigh girth (right)	−2.024	2.490	−0.050	−0.813	0.418
	Body height	6.055	0.991	0.249	6.111	0.000
	Buttock girth	−7.457	1.860	−0.219	−4.009	0.000
	Mid-neck girth	10.517	2.635	0.186	3.991	0.000

Coefficients[a]

Model		Nonstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. error	Beta		
6	(Constant)	56.615	194.877		0.291	0.772
	Weight	15.131	1.375	0.771	11.001	0.000
	Body height	6.504	0.822	0.268	7.916	0.000
	Buttock girth	−8.266	1.569	−0.243	−5.269	0.000
	Mid-neck girth	11.180	2.502	0.197	4.469	0.000

[a]Dependent variable: predicted basal metabolic rate.

Table 15. Regression coefficient.

Variables entered/removed[a]

Model	Variables entered	Variables removed	Method
1	Mid-neck girth	—	Stepwise (criteria: probability-of-F-to-enter ≤ 0.005, probability-of-F-to-enter ≥ 0.100)
2	Body height	—	Stepwise (criteria: probability-of-F-to-enter ≤ 0.005, probability-of-F-to-enter ≥ 0.100)

[a]Dependent variable: measured basal metabolic rate.

Table 16. Modeling.

Model	R	R square	Adjusted R square	Std. error of the estimate
1	0.473[a]	0.223	0.216	254.233
2	0.502[b]	0.252	0.239	250.619

[a]Measure variables: (constant), mid-neck girth.
[b]Measure variables: (constant), mid-neck girth, body height.

Table 17. Model summary.

According to **Table 16**, the mid-neck girth and body height variables can be embedded into the model. The goodness of fit of model 2 is better than model 1, but the R value of the model 2 is 0.252, which indicates that independent variable can explain the change of dependent variable 25.2% (**Table 17**). In the model regression analysis, the goodness of fit is general. In addition, for the probability of F value greater than F critical value (sig.) which is about 0.000, we can deduce that there are correlations between measured basal metabolic rate and the mid-neck girth, measured basal metabolic rate, and body height, respectively (**Table 18**).

In the light of **Table 19**, since P values of the two independent variables are 0.000 and 0.042, respectively, the mid-neck girth and body height are related to the basal metabolic rate. Meanwhile, after considering all the factors of the independent variable, we can deduce the final regression equation: Y = −1128.222 + 38.379 × mid-neck girth + 8.940 × body height.

Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	2081624.638	1	2081624.638	32.206	0.000[a]
	Residual	7239032.599	112	64634.220		
	Total	9320657.237	113			
2	Regression	2348739.947	2	1174369.974	18.697	0.000[b]
	Residual	6971917.290	111	62810.066		
	Total	9320657.237	113			

[a]Measure variables: (constant), mid-neck girth.
[b]Measure variables: (constant), mid-neck girth, body height.
[c]Dependent variable: measured basal metabolic rate.

Table 18. Anova.

Coefficients[a]

Model		Nonstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. error	Beta		
1	(Constant)	−22.175	287.115		−0.077	0.939
	Mid-neck girth	49.413	8.707	0.473	5.675	0.000
2	(Constant)	−1128.222	606.438		−1.860	0.065
	Mid-neck girth	38.379	10.114	0.367	3.795	0.000
	Body height	8.940	4.335	0.199	2.062	0.042

[a]Dependent variable: measured basal metabolic rate.

Table 19. Regression coefficient.

4. Conclusions

In this study, after undertaking the factor analysis, linear regression analysis, univariate analysis, and other analysis methods, we can draw the following conclusions:

1. There is commonality among three dimensional body measurement data, embracing maximum belly circumference, waist girth, bust girth (horizontal), thigh girth (right), buttock girth, weight, across shoulder, mid-neck girth, waist height, neck height, bust height, buttock height, and body height, which can be well divided into girth and height factor, with the waist girth, maximum belly circumference, bust girth (horizontal), thigh girth (right), buttock girth, weight, across shoulder, and mid-neck girth included in the girth factor, while waist height, neck height, bust height, buttock height, and body height contained in the height factor.

2. Girth and height factors are correlated with the predicted basal metabolic rate as well as the measured basal metabolic rate. They have a significant linear relationship with the

predicted basal metabolic rate, whereas there is no significant linear relation between the two factors and the measured basal metabolic rate.

3. There are several variables linearly related to the predicted basal metabolic rate and basal metabolic rate, embracing waist girth, maximum belly circumference, bust girth (horizontal), thigh girth (right), buttock girth, weight, across shoulder, mid-neck girth, and body height. The predicted basal metabolic rate is in a significant correlation with weight, body height, buttock girth, and mid-neck girth, while the basal metabolic rate is correlated with mid-neck girth and body height.

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