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Araştırma Makalesi/Research Article

Statistical Selection of Effective Body Measurements: Waist Circumference Measurement Exercise

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Abstract

In this research, normality assumptions of body measurements are conducted according to five criteria, boxplots, and Kolmogorov-Smirnov and Shapiro-Wilk tests and proved normal. Besides, statistical selection of effective body measurements to define other body measurements is proposed for shorter, precise, time-cost saving. To support this proposel, correlation coefficients and multivariate multiple regression analyses (MMRAs) are conducted. Statistical selection of effective body measurements depend upon high correlation coefficient pairs of body measurements bases. MMRAs are handled from three different points of view; first, one body measurement being the dependent variable and other body measurements being independent variables enter Method; second, the same stepwise Method; and third, one body measurement being the dependent variable and statistically selected effective body measurements being independent variables enter Method; finally their Adj.r2's are compared. This research progressed by working on each body measurement, but the waist circumference measurement is only presented here. Enter and stepwise methods concluded the highest and similar results, unexpectedly proposing the least statistical selection of effective body measurements. More profound work with different mathematical sciences will be implemented further.

Keywords: Body Measurement, Assumptions of Normality, Correlation, Multivariate Multiple Regression Analyses, Statistical Selection

Etkili Beden Ölçülerinin İstatistiksel Seçimi: Bel Çevresi Ölçüsü Örneği

Özet

Bu araştırmada beden ölçülerinin normallik varsayımları; beş kriter kullanılarak, Boxplot, Kolmogorov-Smirnov ve Shapiro-Wilk testleri ile gerçekleştirilmiş ve beden ölçülerinin normal dağılım gösterdiği kanıtlanmıştır. Ayrıca, etkili beden ölçülerinin istatistiksel seçimi ile diğer beden ölçülerine ulaşmak için kısa, hassas, zaman ve maliyet tasarruflu bir yöntem önerilmiştir. Bu öneriyi desteklemek için korelasyon katsayıları ve çok değişkenli çoklu regresyon analizleri (MMRA) yapılmıştır. Etkili beden ölçülerinin istatistiksel seçilmesi, yüksek korelasyon katsayılı beden ölçüsü çiftlerinin tespiti temeline dayanmaktadır. MMRAlar ise, üç farklı bakış açışıyla; birinci, bir beden ölçüsü bağımlı değişken ve diğer beden ölçüleri bağımsız değişken enter metodu; ikinci, aynısı stepwise metodu; üçüncü, bir beden ölçüsü bağımlı değişken ve istatistiksel seçilen etkili beden ölçüleri bağımsız değişken enter metodu; olacak şekilde yapılmış ve bunların Adj.r2'leri karşılaştırılmıştır. Her bir beden ölçüsü ayrı ayrı çalışılmış ancak bu çalışmada sadece bel çevresi ölçüsü örnek olarak verilmiştir. Enter ve stepwise metodları en yüksek ve benzer sonuçları vermiş, beklenenin aksine, önerilen en etkili beden ölçülerinin istatistiksel seçimi en düşük sonuçları vermiştir. İleriki çalışmalarda daha derin matematik bilimleri uygulanacaktır.

Anahtar Kelimeler: Beden Ölçüsü, Normallik Varsayımları, Korelasyon, Çok Değişkenli Çoklu Regresyon Analizleri, İstatistiksel Seçim

1. INTRODUCTION

Body measurements and the relationships between body measurements (BM) have long been a concern of many researchers. First of all, BMs are the main concern in apparel production, either tailored or mass produced. In both kinds of production, the goal is to make a garment that fits the person who purchased it. To conform this goal, BMs have to be obtained precisely. BMs are obtained manually, or by body scanners, or by computer software developed recently, which are an immense subject being searched. On the other hand, the relationships between the BMs are also a great subject being searched. The advantage of studying the relationships between BMs is to reach certain BMs without measuring them, instead, to obtain them via the measured ones, spending less time but even attaining more precise meaurements than hand taken ones, besides time and cost saving.

Empirical formulas, statistical methods, or mathematical approaches are applied to reveal the relationships between BMs. Empirical formulas are based on experimental work and reach BMs almost correctly [1-5]. From the point of statistical methods, correlation and regression analyses are the most used statistical tools and many research can be found in the literature [6-9]. With the development of mathematical sciences, mathematical approaches are also applied for defining BMs, since this is also a recently developing study area; to give examples such as, cross-sectional areas of BMs (Figure 1) [10], extraction of feature points (Figure 2) [11], sharp body silhouettes for obtaining 3D BMs from 2D images (Figure 3) [12]; and pixel coordinates for obtaining 3D BMs from 2D images (Figure 4) [13].

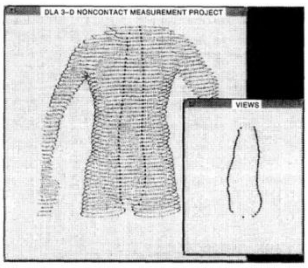


Figure 1. Developing software to extract body measurements [10]

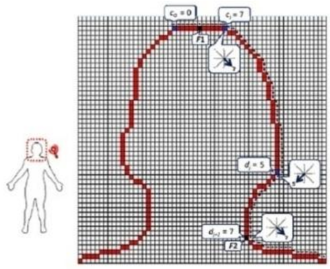
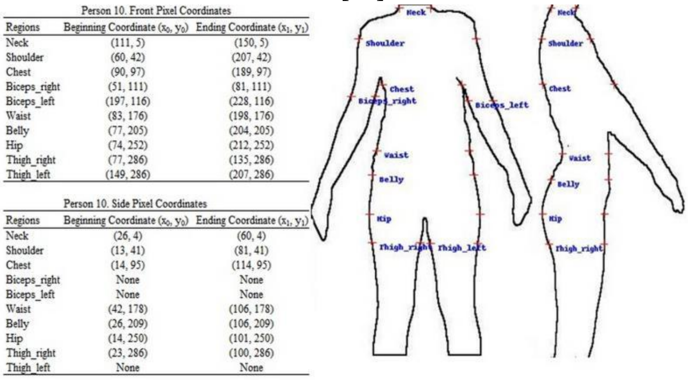


Figure 2. Extraction of feature points F1 and F2 for head size [11]

Figure 3. Background removed image and silhouette image [12]



Person 10. Front Pixel Coordinates

Regions	Beginning Coordinate (x_0, y_0)	Ending Coordinate (x_1, y_1)
Neck	(111, 5)	(150, 5)
Shoulder	(60, 42)	(207, 42)
Chest	(90, 97)	(189, 97)
Biceps_right	(51, 111)	(81, 111)
Biceps_left	(197, 116)	(228, 116)
Waist	(83, 176)	(198, 176)
Belly	(77, 205)	(204, 205)
Hip	(74, 252)	(212, 252)
Thigh_right	(77, 286)	(135, 286)
Thigh_left	(149, 286)	(207, 286)

Person 10. Side Pixel Coordinates

Regions	Beginning Coordinate (x_0, y_0)	Ending Coordinate (x_1, y_1)
Neck	(26, 4)	(60, 4)
Shoulder	(13, 41)	(81, 41)
Chest	(14, 95)	(114, 95)
Biceps_right	None	None
Biceps_left	None	None
Waist	(42, 178)	(106, 178)
Belly	(26, 209)	(106, 209)
Hip	(14, 250)	(101, 250)
Thigh_right	(23, 286)	(100, 286)
Thigh_left	None	None

Figure 4. List of pixel coordinates of feature points for front and side and body silhouettes [13]

In previous research of the correspondent author, a study was initiated to obtain 3D BMs from 2D images to eliminate the need for the body when taking BMs manually or by body scanners, and to investigate a solution to the problem of unfit garment one's own body, which often occurs in e-shopping. The photographs of 500 female participants between ages 18-25, all volunteers, between weights 43-85 kg, wearing tight clothes, from 3 m distance, from the front and side rotated 90^0, from neck to knees, arms and legs slightly open, using a camera that focuses on the waist and parallel to the ground, were taken. Some examples of the photographs taken from the front and side are given in Figure 5, Person-38, Person-119, Person-164, and Person-425, numbered by the author. Different BMs up to 20 (Horizontal : neck, shoulder, biceps, chest, waist, belly, hip, thigh circumferences, back neck girth, back width, shoulder width; and Vertical : inner leg, outer leg, inner arm, front, back, side lengths, arm length from neck, arm length from shoulder, chest fall) were manually measured according to ISO-8559 standards using a non-stretchable tape measure, and the same person's age, height, and weight were also recorded [14, 15].

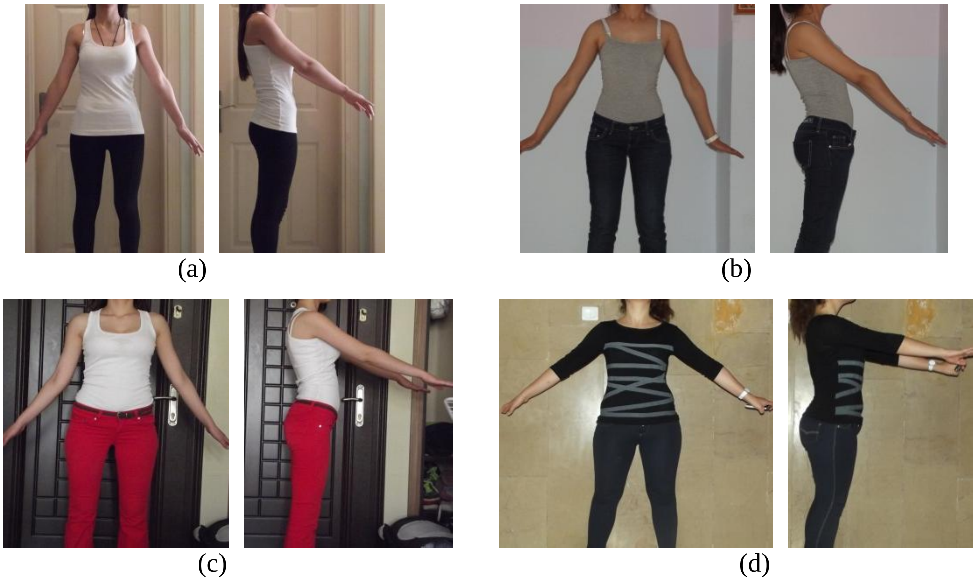


Figure 5. Front and side photographs of volunteers named (a) person-38, (b) person-119, (c) person-164, and (d) person-425 [14, 15]

Since running that research, it was noticed in literature papers applying statistical methods to BMs did not mainly first check the normality of BM data; which seems rather important. Because sample size, if mean represents the data set for comparison, parametric or nonparametric test decision, all depend on the normality assumption of data. Another important point noticed is that the BMs selected to define a specific BM with regression analyses were chosen at random. Still, it was thought that there has to be a reasonable selection. Therefore, these two points are emphasized and discussed in this manuscript; initially, the normality assumptions of BMs are presented, and afterward, statistical selection is conducted to determine a specific BM by regression analysis, not in the literature. This research aims to prove the normality assumptions of BMs and reach the BMs with regression analyses, especially, multivariate multiple regression analyses (MMRAs), both with all BMs and with statistically selected BMs, not randomly.

The steps followed in this research are defining the descriptive statistics of BMs; executing assumptions of normality with its five criteria, boxplots, and Kolmogorov-Smirnov and Shapiro-Wilk tests. This research uses correlation analyses for the statistical selection of MMRAs both with all the BMs and the statistically selected effective BMs. The last comparision tests whether the thought of statistical selection conforms to determining the relationships between some BMs to reach others.

2. MATERIAL AND METHOD

2.1. Material

To realize the purpose of this research, the material used is mainly BMs of female volunteers in Ref. [14,15]. The different BMs concerned here are up to 20 which are Neck Circumference (Circ.), Shoulder Circ., Biceps Circ., Chest Circ., Waist Circ., Belly Circ., Hip Circ., Thigh Circ., Back Neck Girth, Back Width, Shoulder Width, Inner Leg Length, Outer Leg Length, Inner Arm Length, Front Length, Back Length, Side Length, Arm Length1 (from the neck to the wrist), Arm Lenght2 (from shoulder to wrist), and Chest Fall. These BMs are obtained manually according to ISO-8559 standards using a non-stretchable tape measure, and the same person's age, height and weight are also recorded. Schematic presentations of the BMs mentioned above are given in Figure 6 [16].

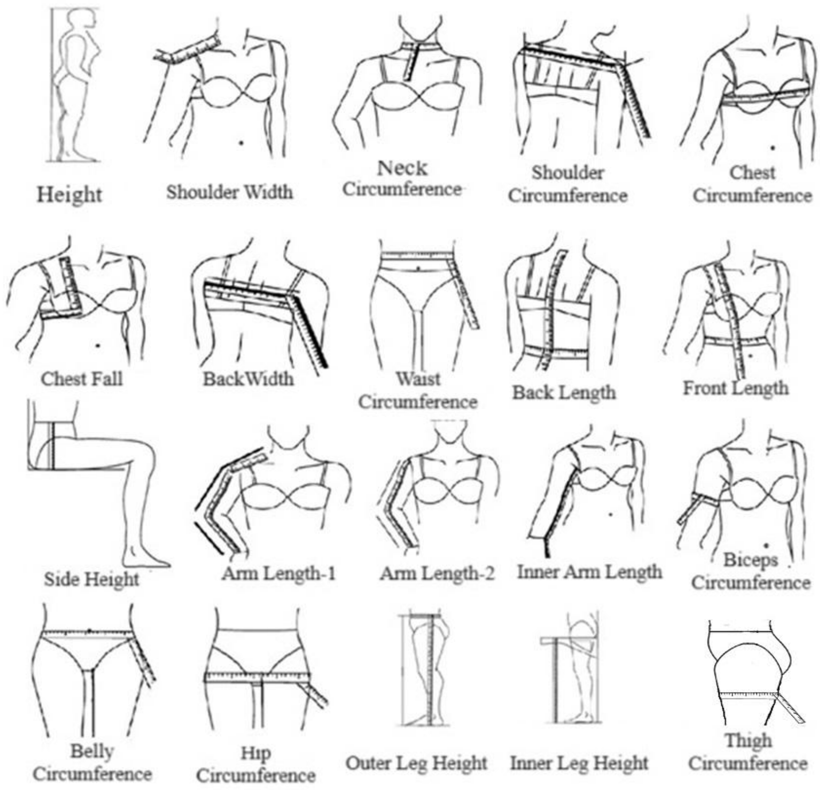


Figure 6. Examples of obtaining body measurements manually [16]

There are 500 female volunteers, consequently, 500 values for each of the 23 BMs are entered in the SPSS IBM Statistics (v23) Package software. Even though there are 500 values for each measurement, 50 of them are separated by the SPSS software for validation at the end of the research, so the rest of the study in this manuscript is continued with 450 values for each BM.

2.2. Method

In this research, the 450 values of each BM are experimented with statistical methods to reach its objective. The statistical methods applied are listed below:

2.2.1. Descriptive statistics

Descriptive statistics of BMs are presented to reach a brief understanding of the data which was obtained manually from the person's body and will be used in the following research step. The descriptive statistics here are the mean, standard error of the mean, median, mode, minimum, maximum, range, standard deviation, variance, skewness, kurtosis, coefficient of variation, standard error of skewness, and standard error of kurtosis.

2.2.2. Assumptions of normality

The criteria of normality assumptions, boxplots, and Kolmogorov-Smirnov and Shapiro-Wilk tests are regarded assumptions of normality. These methods are conducted in this research to study the normality assumptions of BM data.

Criteria of Normality Assumptions

In statistics literature, data normality assumptions are analyzed by considering the five standard distribution criteria:

1. Mean, median and mode values should be equal or close to each other;

2. Histograms should look like a standard distribution curve;
3. Skewness and kurtosis coefficients should be between -1 / +1 ;
4. A standard Q-Q plot should include points above or below but close to a 45^0 diagonal line;
5. CV% should be less than 25%.

If the data meets at least three of the five criteria listed above, it can be pronounced as displaying a normal distribution [17]. These criteria are applied to the BM data in the current research.

Boxplots

Boxpots are data charts with median values and interquartile ranges that point out the extremes and outliers within a variable. A boxpot shows the first quartile, median, third quartile, and minimum-maximum values [17, 18]. This research performs boxplots to visually assess normal distribution, outliers, and extreme values within the studied BM data.

Kolmogorov-Smirnov and Shapiro-Wilk Tests

Kolmogorov-Smirnov and Shapiro-Wilk tests are another test method for assumptions of normality. The suitability of the quantitative data to the normal distribution is tested with the Kolmogorov-Smirnov test when the sample size is $n \geq 50$, and with the Shapiro-Wilk test when $n < 50$, where it has more power to detect the non-normality. However, it can also be handled on larger sample sizes. Suppose their test results are $p > 0.05$ (statistically insignificant). In that case, the data is considered normally distributed, but normal distribution should not be decided based only on the p value of the Kolmogorov-Smirnov and Shapiro-Wilk tests alone. The important thing is that the data should also comply with the five criteria of normal distribution [17, 18]. In this research, Kolmogorov-Smirnov and Shapiro-Wilk tests are performed for assumptions of normality of BM data.

2.2.3. Correlation coefficients

The statistical analyses above determine which BMs exhibit normal distribution and to what extent. According to the information obtained, Pearson correlation coefficients, r, between each BM is calculated. The value of the coefficient indicates the strength of the relationship and the sign the direction, that is, the higher the correlation coefficient the stronger the relationship between that pair, and if a positive value it means that as one increases the other also increases; if a negative value it means that as one increases the other decreases. r can take a value between $-1 / +1$, and regardless of the sign, values between 0.10-0.29 mean a weak correlation, 0.30-0.49 medium correlation, 0.50-1.00 strong correlation; besides, the $p < 0.05$ means that it is statistically significant [19].

In the current research, the correlation coefficients between each BM are listed from high to low to determine which BM affected the other BM the most and up to which degree. BMs with r greater than $+0.5$ ($r>+0.5$) are selected which symbolizes a strong correlation, this selection indicates they are the effective body measurements on a special BM. This is the statistical selection of effective BMs proposed in this paper. The statistically selected effective BMs are beneficial for determining a special BM for the comparisons.

2.2.4. Regression analyses

Regression analyses are conducted in cases where a parameter can be determined with the data of other parameters, and they are called the dependent variable and independent variables, respectively. Multivariate Multiple Regression Analyses (MMRAs) can further be used to model the linear relationship between more than one independent variable and more than one dependent variable [20]. In the current research, regression analyses are conducted with three different points of view for each BM one by one: 1) dependent variable is one of the BMs, independent variable is rest of the BMs, enter method; 2) dependent variable is one of the BMs, independent variable is rest of the BMs, stepwise method; and 3) dependent variable is one of the BMs, independent variable is the statistically selected effective BMs, enter method. The stepwise method is not conducted because correlation analyses already selected variables, no more selection is needed (Table 1).

Table 1. Multivariate multiple regression analyses conducted in this research

Dependent Variable	Independent Variable	Method	Results
1. One body meausurement	Rest of the body measurements	Enter	r^2's , Adj.r^2's
2. One body meausurement	Rest of the body measurements	Stepwise	r^2's , Adj.r^2's
3. One body meausurement	Statistically selected body measurements	Enter	r^2's , Adj.r^2's

2.2.5. Comparisons

The r^2's and Adj.r^2's results obtained by MMRAs are compared; where; Lines 1, 2 and 3 in Table 1, are compared to determine if there is a difference in applying the rest of the BMs as independent variables enter and stepwise methods and the statistically selected BMs as independent variables enter method. This comparison assesses the accuracy and adequate Method for the BM data.

2.2.6. Validation

It was mentioned above that there were BMs of 500 female volunteers but 50 were separated for the validation group at the beginning of the research. In this section, the information obtained by comparison is intended to be applied to this test group and the estimated BMs are aimed to be obtained. The estimated BMs and the manually taken BMs results are intended to compare and calculate their accuracy rates.

3. RESULTS AND DISCUSSIONS

The results of the statistical methods and the selected BMs described in Section 2. Material and Method are presented and discussed in this section.

3.1. Descriptive Statistics

Descriptive statistics of BMs are presented to attain a brief understanding of the data and to be used in the normality assumptions of BM data. The descriptive statistics of BMs studied in this research presented in Table 2 are the mean, standard error of the mean, median, mode, minimum, maximum, range, standard deviation, variance, skewness, kurtosis, coefficient of variation (CV%), standard error of skewness, and standard error of kurtosis.

Table 2. Descriptive statistics of body measurements studied in this research

Descriptive Statistics													
	N	Mean	Std. Error of Mean	Median	Mode	Minimum	Maximum	Range	Std. Deviation	Variance	Skewness[b]	Kurtosis[c]	Coefficient of Variation (%CV)
Height	450	164.531	0.245	165.0	160.0	150.0	176.0	26.0	5.203	27.074	-0.033	-0.482	3.162
Weight (kg)	450	55.993	0.351	55.0	55.0	42.0	85.0	43.0	7.447	55.452	1.123	1.877	13.299
Neck Circ.	450	31.040	0.082	31.0	31.0	26.0	36.0	10.0	1.733	3.005	0.430	0.560	5.584
Back Neck Girth	450	13.965	0.063	14.0	13.0	11.0	19.0	8.0	1.334	1.779	0.595	0.543	9.549
Shoulder Width	450	13.468	0.060	13.2	13.0	10.0	18.0	8.0	1.264	1.597	0.236	0.347	9.384
Shoulder Circ.	450	95.722	0.266	95.0	94.0	75.0	121.0	46.0	5.650	31.921	0.519	1.809	5.902
Chest Circ.	450	86.756	0.281	85.8	84.0[a]	74.0	109.0	35.0	5.964	35.574	0.882	1.126	6.875
Chest Fall	450	24.893	0.089	25.0	24.0	20.0	32.0	12.0	1.878	3.527	0.548	0.745	7.545
Back Width	450	35.771	0.129	36.0	36.0	29.0	47.0	18.0	2.726	7.432	0.544	1.225	7.621
Waist Circ.	450	69.922	0.286	69.0	68.0	59.0	97.0	38.0	6.058	36.699	1.143	2.264	8.664
Back Length	450	34.123	0.112	34.0	33.0	28.0	42.5	14.5	2.368	5.608	0.501	0.522	6.940
Front Length	450	36.881	0.135	37.0	38.0	29.0	46.0	17.0	2.868	8.225	0.320	0.368	7.776
Side Lenght	450	16.447	0.138	16.0	15.0	10.5	26.0	15.5	2.923	8.545	0.610	-0.122	17.773
Arm Length1	450	66.844	0.161	67.0	68.0	58.0	78.0	20.0	3.418	11.683	0.240	0.217	5.113
Arm Length2	450	55.370	0.151	55.2	56.0	47.0	63.0	16.0	3.203	10.262	0.084	-0.100	5.785
Inner Arm Lengt	450	43.934	0.117	44.0	45.0	34.0	55.0	21.0	2.475	6.126	0.043	1.618	5.633
Biceps Circ.	450	25.067	0.123	25.0	26.0	19.0	35.0	16.0	2.614	6.831	0.575	0.247	10.427

Belly Circ.	450	79.829	0.328	79.0	78.0	66.0	108.0	42.0	6.963	48.489	0.642	0.895	8.723
Hip Circ.	450	95.965	0.289	96.0	98.0	82.0	120.0	38.0	6.135	37.641	0.674	1.421	6.393
Outer Leg Lengt	450	92.650	0.300	93.0	90.0	74.0	112.0	38.0	6.363	40.486	0.089	-0.323	6.868
Inner Leg Length	450	66.844	0.179	66.0	65.0	57.0	80.0	23.0	3.792	14.377	0.308	-0.225	5.672
Thigh Circ.	450	52.012	0.206	52.0	53.0	39.0	65.0	26.0	4.376	19.148	0.463	0.448	8.413

a. Multiple modes exist. The smallest value is shown

b. Std. Error of Skewness 0.115

c. Std. Error of Kurtosis 0.230

3.2. Assumptions of Normality

3.2.1. Criteria of normality assumptions

Each BM is evaluated according to the five criteria of normality assumptions listed in Section 2.2. The overall evaluation is summarized in Table 3. If at least three of these five criteria are met by the data of a specific BM, then it can be pronounced that it exhibits a normal distribution listed as 3/5, 4/5, or 5/5 in the last column of Table 3.

Table 3. Overall evaluation of normality assumption criteria for all body measurements

Normal Distribution Assumptions / Descriptive Statistics									
	1. Criterion: mean, mode and median are close to each other			2. Criterion: The histogram distribution of the data is Normal Distribution	3. Criterion: Skewness and kurtosis coefficients are between -1/+1		4. Criterion: Normal Q-Q plot graph, with points above (or very close to) 45^0 lines	5. Criterion: The coefficient of variation (CV%) is below 25%	Conclusion
	Mean	Median	Mode		Skewness[b]	Kurtosis[c]	Normal Q-Q plot graph	Coefficient of Variation (CV%)	How many of the five criteria does this body measure meet?
Height	164.531	165.00	160.0	Normal Distr.	-0.033	-0.482	Very close to 45^0	3.162	4/5
Weight	55.993	55.00	55.0	Normal Distr.	1.123	1.877	Very close to 45^0	13.299	3/5
Neck Circ.	31.040	31.00	31.0	Normal Distr.	0.430	0.560	Very close to 45^0	5.584	5/5
Back Neck Girt	13.965	14.00	13.0	Normal Distr.	0.595	0.543	Very close to 45^0	9.549	5/5
Shoulder Width	13.468	13.20	13.0	Normal Distr.	0.236	0.347	Very close to 45^0	9.384	5/5
Shoulder Circ.	95.722	95.00	94.0	Normal Distr.	0.519	1.809	Very close to 45^0	5.902	3/5
Chest Circ.	86.756	85.80	84.0[a]	Normal Distr.	0.882	1.126	Very close to 45^0	6.875	3/5
Chest Fall	24.893	25.00	24.0	Normal Distr.	0.548	0.745	Very close to 45^0	7.545	5/5
Back Width	35.771	36.00	36.0	Normal Distr.	0.544	1.225	Very close to 45^0	7.621	4/5
Waist Circ.	69.922	69.00	68.0	Normal Distr.	1.143	2.264	Very close to 45^0	8.664	3/5
Back Length	34.123	34.00	33.0	Normal Distr.	0.501	0.522	Very close to 45^0	6.94	4/5
Front Length	36.881	37.00	38.0	Normal Distr.	0.320	0.368	Very close to 45^0	7.776	4/5
Side Height	16.447	16.00	15.0	Normal Distr.	0.610	-0.122	Very close to 45^0	17.773	4/5
Arm Length-1	66.844	67.00	68.0	Normal Distr.	0.240	0.217	Very close to 45^0	5.113	4/5
Arm Length-2	55.370	55.20	56.0	Normal Distr.	0.084	-0.100	Very close to 45^0	5.785	5/5
Inner Arm Leng	43.934	44.00	45.0	Normal Distr.	0.043	1.618	Very close to 45^0	5.633	3/5
Biceps Circ.	25.067	25.00	26.0	Normal Distr.	0.575	0.247	Very close to 45^0	10.427	5/5
Belly Circ.	79.829	79.00	78.0	Normal Distr.	0.642	0.895	Very close to 45^0	8.723	4/5
Hip Circ.	95.965	96.00	98.0	Normal Distr.	0.674	1.421	Very close to 45^0	6.393	3/5
Outer Leg Heigh	92.650	93.00	90.0	Normal Distr.	0.089	-0.323	Very close to 45^0	6.868	4/5
Inner Leg Heigh	66.844	66.00	65.0	Normal Distr.	0.308	-0.225	Very close to 45^0	5.672	4/5
Thigh Circ.	52.012	52.00	53.0	Normal Distr.	0.463	0.448	Very close to 45^0	8.413	5/5

a. Multiple modes exist. The smallest value is shown

b. Std. Error of Skewness 0.12

c. Std. Error of Kurtosis 0.23

Each criterion is studied separately below:

1. Mean, median, and mode values should be equal or close to each other;

Each BM's mean, median, and mode values seem to be quite equal or close. Their equality and closeness are tested by *t*-tests for each BM one by one, but as an example, only the *t*-test conducted for the waist circumference measurement (WCM) is given below:

Mean, median, and mode values should be equal or close to each other:
Waist Circumference example

WCMs are mean 69.922 cm, median 69 cm, and mode 68 cm. *t*-tests are performed to determine whether there is a statistically significant difference between the mean and median values, and mean and mode values (Table 4). In Table 4, Sig.(2-tailed) $p = 0.001$, and since $p < 0.05$, it is seen that there is a statistically significant difference between the mean-median and mean-mode values. It is stated that this criterion does not satisfy the necessary condition of normality assumption, hence the number of criteria met by WCM is 0/5 now.

Table 4. t-test between mean and median values of waist circumference

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Waist Circumference	450	69.922	6.0580	0.2856

One-Sample Test

	Test Value = 69 (Median)					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Waist Circumference	3.228	449	0.001	0.9218	0.361	1.483

One-Sample Test

	Test Value = 68 (Mode)					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Waist Circumference	6.730	449	0.000	1.9218	1.361	2.483

2. Histograms should look like a standard distribution curve;

The histogram of each BM is prepared and each of them displays somehow a symmetrical distribution around the mean in the form of a normal distribution curve. They are assessed visually one by one, but as an example, only the histogram of WCM is given below:

Histograms should look like a normal distribution curve:

Waist Circumference example

The histogram of WCM is given in Figure 7. When assessed visually, the histogram of WCM presents a normal distribution curve and also drawn in Figure 7. It is stated that this criterion satisfies the necessary condition of normality assumption, hence the number of criteria met by WCM is 1/5 up to now.

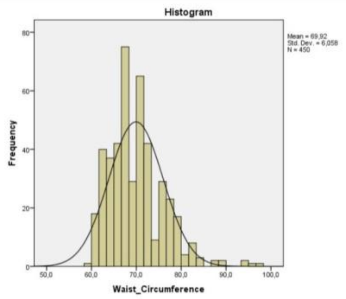


Figure 7. Histogram of waist circumference values

3. Skewness and kurtosis coefficients should be between -1 / +1 ;

Each BM's skewness and kurtosis values are analyzed if the values lie between - 1 / + 1 . In the skewness column of Table 2, coefficients vary between -0.033 and 1.143 . In the same table's kurtosis column, values vary between -0.482 and 2.264 . One by one, an analysis of each BM is carried on, but as an example, only the analysis of the WCM is given below:

Skewness and kurtosis coefficients should be between -1 / +1 :
Waist Circumference example

The skewness coefficient of WCM in Table 2 is 1.143 , when analyzed if it is between - 1 / + 1 , it is clearly seen that it is out of the higher limit of + 1. The kurtosis coefficient of WCM in the same table is 2.264 , when analyzed if it is between - 1 / + 1 , it is clearly seen that it is out of the higher limit of + 1 . It is stated that this criteria does not satisfy the necessary condition of normality assumption, hence, the number of criteria met by WCM is still 1/5 up to now.

4. A standard Q-Q plot should include points above or below but close to a 45^0 diagonal line;

The normal Q-Q plot of each BM is drawn and each somehow includes points above or below but close to a 45^0 diagonal line. They are assessed visually one by one, but as an example, only the normal Q-Q plot of WCM is given below:

A standard Q-Q plot should include points above or below but close to a 45^0 diagonal line:
Waist Circumference example

The normal Q-Q plot of WCM is given in Figure 8. When assessed visually, the normal Q-Q plot of WCM includes points above or below but is close to a 45^0 diagonal line. It is stated that this criterion satisfies the necessary condition of normality assumption, hence, the number of criteria met by WCM is 2/5 up to now.

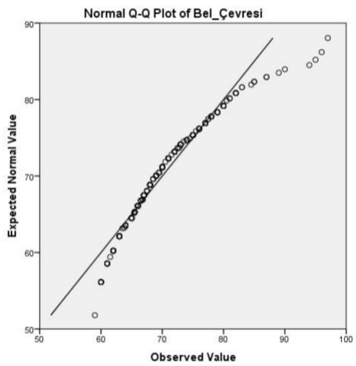


Figure 8. Normal Q-Q plot of waist circumference values

5. CV% should be less than 25% .

The CV% values of each BM are analyzed if the values are less than 25% . In the CV% column of Table 2, values vary between 3.162% and 17.773% . One by one, an analysis of each BM is carried on, but as an example, only the analysis of the WCM is given below:

CV% should be less than 25% :
Waist Circumference example

The CV% value of WCM is 8.664% , when analyzed if it is less than 25% , it is clearly seen that it is. It is stated that this criterion satisfies the necessary condition of normality assumption, hence, the number of criteria met by WCM is 3/5 up to now.

Since the WCM meets the 3 out of 5 necessary conditions of normality assumptions, it can be pronounced that WCM values display a normal distribution. In general, in the last column of Table 2, it is seen that six of the BMs meet 3/5 criteria of normality assumptions, nine of the BMs meet 4/5 criteria, and eight of the BMs meet 5/5 criteria, in general, it can be pronounced that all the different BM values studied in this research display normal distribution.

3.2.2. Boxplots

Boxplots are performed for each BM, and each BM's first quartile, median, third quartile, minimum-maximum values, outliers, and extreme values of each BM are assessed visually individually. The boxplots of all BMs are given in Figure 9. It is noticed that within the studied BMs, there are outliers and extreme values, high and low, in most of them. Even though it can be pronounced that they are distributed normally in Section 3.2.1., the boxplots precisely indicate the value's behavior; none of the BMs display a perfect normal distribution visually.

For example, the boxplot of the WCM values is given in Figure 10, which is enlarged. In particular, the outliers and extreme values are clearly seen, where the numbers on the boxplot indicate the number of the volunteers the authors gave. Which person possesses the outliers and extreme values for further research is evaluated.

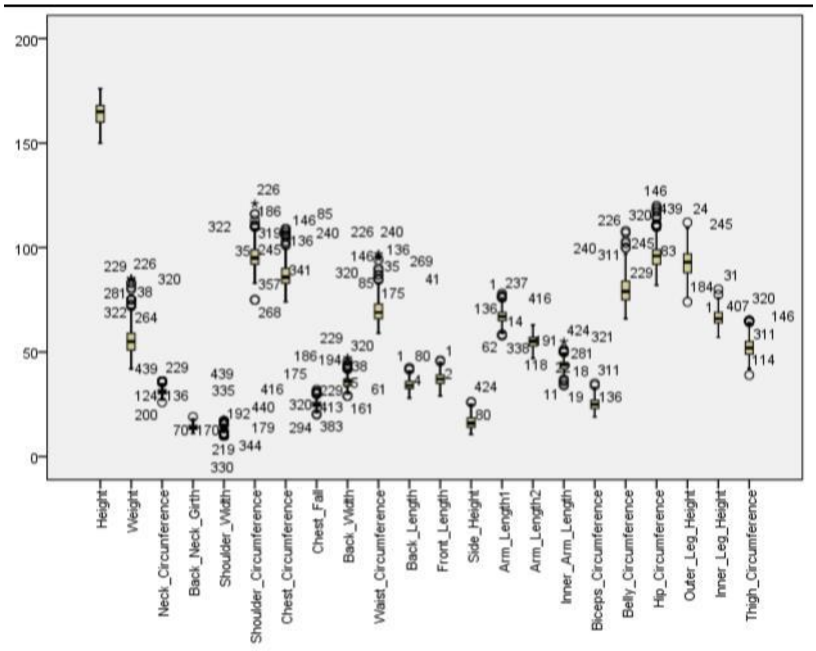


Figure 9. Number of people who have outliers with boxplot chart (n=450)

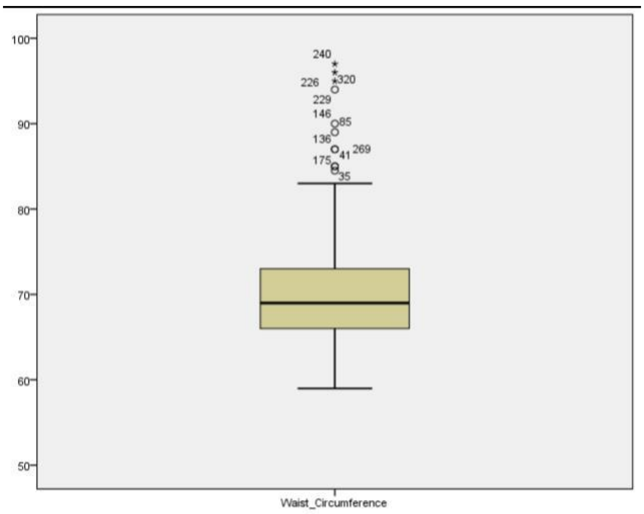


Figure 10. Boxplot of waist circumference values

3.2.3. Kolmogorov-smirnov and shapiro-wilk tests

Kolmogorov-Smirnov and Shapiro-Wilk tests are performed for each BM with each having 450 values in this research. Their p values are evaluated if $p > 0.05$ where statistically insignificance means normal distribution. According to both Kolmogorov-Smirnov and Shapiro-Wilk test results given in Table 5, all BMs are analyzed individually and they possess $p < 0.05$, meaning that none display normal distribution. Even though it can be pronounced that the BM data are distributed normally in Section 3.2 1., the Kolmogorov-Smirnov and Shapiro-Wilk tests indicate the opposite. It is evaluated that the outliers and extreme values visually assessed in boxplots are considered mathematically in these tests, none of the BMs display a normal distribution perfectly.

Table 5. Kolmogorov-Smirnov and Shapiro-Wilk test results

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Height	0.099	450	0.000	0.976	450	0.000
Weight	0.129	450	0.000	0.931	450	0.000
Neck Circ.	0.131	450	0.000	0.967	450	0.000
Back Neck Girth	0.161	450	0.000	0.946	450	0.000
Shoulder Width	0.142	450	0.000	0.965	450	0.000
Shoulder Circ.	0.081	450	0.000	0.971	450	0.000
Chest Circ.	0.106	450	0.000	0.954	450	0.000
Chest Fall	0.146	450	0.000	0.965	450	0.000
Back Width	0.102	450	0.000	0.971	450	0.000
Waist Circ.	0.119	450	0.000	0.934	450	0.000
Back Length	0.102	450	0.000	0.972	450	0.000
Front Length	0.081	450	0.000	0.982	450	0.000
Side Height	0.130	450	0.000	0.959	450	0.000
Arm Length-1	0.105	450	0.000	0.986	450	0.000
Arm Length-2	0.078	450	0.000	0.987	450	0.001
Inner Arm Length	0.089	450	0.000	0.974	450	0.000
Biceps Circ.	0.096	450	0.000	0.973	450	0.000
Belly Circ.	0.059	450	0.001	0.975	450	0.000
Hip Circ.	0.083	450	0.000	0.968	450	0.000
Outer Leg Height	0.050	450	0.008	0.994	450	0.075
Inner Leg Height	0.106	450	0.000	0.984	450	0.000
Thigh Circ.	0.068	450	0.000	0.981	450	0.000

a. Lilliefors Significance Correction

An overall evaluation of BM data studied in this research is realized in the light of the information obtained about normal distribution. The assumptions of normality in Section 3.2.1. indicate that each of the BM data displays normal distribution, on the other hand, boxplots in Section 3.2.2., and Kolmogorov-Smirnov and Shapiro-Wilk tests in Section 3.2.3. indicate the opposite. The results of the Kolmogorov-Smirnov and Shapiro-Wilk tests cannot be considered alone for normal distribution. Consequently boxplots show the behavior of BM data visually related to these tests. The sample size is large with 450 values for each BM. Finally, it is considered that BM data display normal distribution according to the assumptions of normality is proven.

3.3. Statistical Selection of Effective Body Measurements with Correlation Analyses

Correlation coefficients are calculated between each BM studied in this research. In this calculation of correlation coefficients, the Pearson method is conducted because it was proved that BM values display normal distribution in the previous section.

The correlation coefficients between each BM are a total of 231 pairs, 225 of them have positive correlation coefficients ranging between 0.835 and 0.000 , meaning that if one incresases the other increases also, 6 of them have negative correlation coefficients ranging between -0.008 and -0.090 , meaning that if one increases the other further decreases (Table 6). These correlation coefficients are in accordance with the correlation coefficient studies found in literature like chest circumference measurement – height pair, thigh circumference –hip circumference etc., but also differences were noticed like back length – waist circumference, belly circumference – chest circumference, etc. [6-9].

Table 6. Pearson correlation coefficients and significance values for each body measurement

Correlations

		Height	Weight	Neck Circ.	Back Neck Girth	Shoulder Width	Shoulder Circ.	Chest Circ.	Chest Fall	Back Width	Waist Circ.	Back Length	Front Length	Side Height	Arm Length1	Arm Length2	Inner Arm Length	Biceps Circ.	Belly Circ.	Hip Circ.	Outer Leg Height	Inner Leg Height	Thigh Circ.
Height	Pearson Correlation	1																					
	Sig. (2-tailed)																						
Weight	Pearson Correlation	0,395**	1																				
	Sig. (2-tailed)	0,000																					
Neck Circ.	Pearson Correlation	0,221**	0,611**	1																			
	Sig. (2-tailed)	0,000	0,000																				
Back Neck Girth	Pearson Correlation	0,094*	0,265**	0,302**	1,000																		
	Sig. (2-tailed)	0,046	0,000	0,000																			
Shoulder Width	Pearson Correlation	0,164**	0,206**	0,070	0,021	1,000																	
	Sig. (2-tailed)	0,000	0,000	0,140	0,651																		
Shoulder Circ.	Pearson Correlation	0,269**	0,683**	0,538**	0,152**	0,264**	1,000																
	Sig. (2-tailed)	0,000	0,000	0,000	0,001	0,000																	
Chest Circ.	Pearson Correlation	0,189**	0,785**	0,591**	0,228**	0,125**	0,673**	1,000															
	Sig. (2-tailed)	0,000	0,000	0,000	0,000	0,008	0,000																
Chest Fall	Pearson Correlation	0,193**	0,454**	0,315**	0,081	0,152**	0,399**	0,496**	1,000														
	Sig. (2-tailed)	0,000	0,000	0,000	0,086	0,001	0,000	0,000															
Back Width	Pearson Correlation	0,222**	0,565**	0,478**	0,218**	0,178**	0,621**	0,576**	0,307**	1,000													
	Sig. (2-tailed)	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000														
Waist Circ.	Pearson Correlation	0,130**	0,774**	0,632**	0,219**	0,101*	0,641**	0,769**	0,459**	0,570**	1,000												
	Sig. (2-tailed)	0,006	0,000	0,000	0,000	0,032	0,000	0,000	0,000	0,000													
Back Length	Pearson Correlation	0,276**	0,231**	0,223**	-0,023	0,229**	0,255**	0,201**	0,164**	0,193**	0,133**	1,000											
	Sig. (2-tailed)	0,000	0,000	0,000	0,629	0,000	0,000	0,000	0,000	0,000	0,005												
Front Length	Pearson Correlation	0,250**	0,320**	0,202**	-0,068	0,365**	0,331**	0,323**	0,494**	0,268**	0,175**	0,380**	1,000										
	Sig. (2-tailed)	0,000	0,000	0,000	0,152	0,000	0,000	0,000	0,000	0,000	0,000	0,000											
Side Height	Pearson Correlation	0,202**	0,093*	0,070	-0,008	0,398**	0,042	0,039	0,053	0,042	-0,090	0,361**	0,624**	1,000									
	Sig. (2-tailed)	0,000	0,049	0,139	0,865	0,000	0,371	0,412	0,259	0,377	0,056	0,000	0,000										
Arm Length1	Pearson Correlation	0,605**	0,444**	0,300**	0,071	0,266**	0,400**	0,268**	0,285**	0,355**	0,275**	0,307**	0,292**	0,164**	1,000								
	Sig. (2-tailed)	0,000	0,000	0,000	0,133	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000									
Arm Length2	Pearson Correlation	0,578**	0,363**	0,229**	0,125**	0,072	0,273**	0,201**	0,172**	0,286**	0,244**	0,169**	0,091	0,020	0,824**	1,000							
	Sig. (2-tailed)	0,000	0,000	0,000	0,008	0,125	0,000	0,000	0,000	0,000	0,000	0,000	0,053	0,676	0,000								
Inner Arm Length	Pearson Correlation	0,623**	0,251**	0,095*	0,068	0,263**	0,170**	0,064	0,078	0,152**	0,014	0,242**	0,226**	0,231**	0,673**	0,661**	1,000						
	Sig. (2-tailed)	0,000	0,000	0,043	0,151	0,000	0,000	0,173	0,099	0,001	0,773	0,000	0,000	0,000	0,000	0,000							
Biceps Circ.	Pearson Correlation	0,042	0,680**	0,548**	0,204**	0,161**	0,587**	0,692**	0,449**	0,425**	0,724**	0,198**	0,265**	0,039	0,237**	0,178**	-0,033	1,000					
	Sig. (2-tailed)	0,378	0,000	0,000	0,000	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,405	0,000	0,000	0,488						
Belly Circ.	Pearson Correlation	0,195**	0,759**	0,531**	0,163**	0,164**	0,649**	0,710**	0,493**	0,465**	0,763**	0,254**	0,319**	0,068	0,331**	0,246**	0,172**	0,652**	1,000				
	Sig. (2-tailed)	0,000	0,000	0,000	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,151	0,000	0,000	0,000	0,000					
Hip Circ.	Pearson Correlation	0,210**	0,835**	0,605**	0,245**	0,211**	0,661**	0,725**	0,433**	0,516**	0,765**	0,197**	0,258**	0,047	0,344**	0,288**	0,128**	0,721**	0,728**	1,000			
	Sig. (2-tailed)	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,316	0,000	0,000	0,006	0,000	0,000				
Outer Leg Height	Pearson Correlation	0,665**	0,301**	0,150**	0,066	0,222**	0,119*	0,156**	0,207**	0,118*	0,100*	0,276**	0,339**	0,383**	0,352**	0,255**	0,419**	0,026	0,189**	0,151**	1,000		
	Sig. (2-tailed)	0,000	0,000	0,001	0,160	0,000	0,011	0,001	0,000	0,012	0,034	0,000	0,000	0,000	0,000	0,000	0,000	0,589	0,000	0,001			
Inner Leg Height	Pearson Correlation	0,719**	0,267**	0,074	0,000	0,215**	0,168**	0,125**	0,169**	0,128**	0,052	0,198**	0,241**	0,253**	0,519**	0,487**	0,659**	0,028	0,205**	0,135**	0,642**	1,000	
	Sig. (2-tailed)	0,000	0,000	0,116	0,997	0,000	0,000	0,008	0,000	0,007	0,274	0,000	0,000	0,000	0,000	0,000	0,000	0,561	0,000	0,004	0,000		
Thigh Circ.	Pearson Correlation	0,082	0,724**	0,518**	0,182**	0,128**	0,530**	0,657**	0,389**	0,415**	0,662**	,115*	0,217**	0,063	0,148**	0,110*	-0,020	0,703**	0,629**	0,778**	0,180**	0,060	1,000
	Sig. (2-tailed)	0,083	0,000	0,000	0,000	0,006	0,000	0,000	0,000	0,000	0,000	0,015	0,000	0,184	0,002	0,020	0,673	0,000	0,000	0,000	0,000	0,205	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The 231 correlation coefficients of BMs are listed in pairs from high to low to determine which BM affected the other BM the most and up to which degree.. BM pairs having correlation coefficients r greater than $+0.5$ ($r > +0.5$) and $p < 0.05$ are selected because it is evaluated that they demonstrate a strong relationship between the BM pairs and are the effective BM on a special BM. It is what is meant by statistical selection purpose in this research. 53 of them, which suffice $r > +0.5$ and $p < 0.05$ are listed which were selected among the 231. These selected BMs benefited from the rest of this research to determine a special BM by other BMs one by one.

Following the objective of this research, the statistical selection of effective BMs, WCM is given as an example. WCM pairs having correlation coefficients $r > 0.5$ strong relationships are selected. There are nine BM pairs which are Waist Cir.-Weight, Waist Cir.-Chest Circ., Waist Cir.-Hip Circ., Waist Circ.-Belly Circ., Waist Cir.-Biceps Circ., Waist Cir.-Thigh Circ., Waist Cir.-Shoulder Circ., Waist Cir.-Neck Circ., and Waist Cir.-Back Width. Their list is given in Table 7. Also, the bar chart of r values is given in Figure 11. Furthermore, these WCM pairs will benefit in the rest of this research.

Table 7. List of nine waist circumference measurement pairs

Number	Body Measurements	Pearson Correlation (r)	Sig.
1	Waist Circ., Weight	0.774	0.000
2	Waist Circ., Chest Circ.	0.769	0.000
3	Waist Circ., Hip Circ.	0.765	0.000
4	Waist Circ., Belly Circ.	0.763	0.000
5	Waist Circ., Biceps Circ.	0.724	0.000
6	Waist Circ., Thigh Circ.	0.662	0.000
7	Waist Circ., Shoulder Circ.	0.641	0.000
8	Waist Circ., Neck Circ.	0.632	0.000
9	Waist Circ., Back Width	0.570	0.000

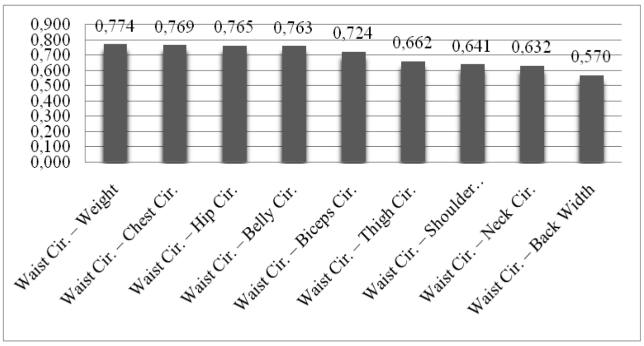


Figure 11. Bar chart of r values of waist circumference measurement pairs

3.4. Regression Analysis

In the current research, one BM is determined by the rest of the BMs but by applying different points of view to MMRAs and the statistically selected effective BMs, which are also used for the approach of shorter, more precise, and time and cost saving. Each BM is studied one by one, and every time one BM is considered as the dependent variable. The rest of the BMs as the independent variables in an MMRA equation, conducted in the first enter method and then stepwise method. The same is repeated with the statistically selected effective BMs where each BM is considered as a dependent variable. The statistically selected effective BMs as the independent variables in an MMRA equation enter method, stepwise method is not needed because the effective BMs are already selected (Table 7 and Figure 11). In each study, the results r^2's, Adj.r^2's and regression coefficients to construct an MMRA equation are noted, and the equations are written. The same work is done for each BM one by one, but as an example, only the MMRA study conducted for the WCM is given below:

Experimenting waist circumference with all the rest of the body measurements enter method

WCM first experiments with all the rest of BMs' enter method. In this case the WCM is the dependent variable in the regression analysis and all the rest of BMs which are the Weight, Height, Chest Circ., Hip Circ., Front Length, Biceps Circ., Inner Leg Length, Outer Leg Length, Back Width, Shoulder Width, Belly Circ., Arm Length1, Arm Length2, Inner Arm Length, Neck Circ., Shoulder Circ., Back Length, Back Neck Girth, Chest Fall, Side Height, and Thigh Circ. are the independent variables, the aim is always to obtain the highest r^2, consequently the Adj.r^2.

The results are given in Table 8 where it is seen in the Model Summary that the obtained r^2 is 0.796 and Adj.r^2 is 0.786, which seems to be quite high, nearly 0,8, in ANOVA Table that $p < 0.05$, which indicates that regression analysis is worth to conduct. In the Regression Coefficient list, it is each BM's effect. Equation 1 is the MMRA equation enter method of WCM with all the rest of the BMs.

Table 8. Model summary, ANOVA table, and regression coefficients enter method of all body measurements to determine waist circumference

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.892[a]	0.796	0.786	2.802

a. Predictors: (Constant), Thigh Circ., Inner Arm Length, Back Neck Girth, Side Height, Chest Fall, Back Length, Shoulder Width, Back Width, Outer Leg Height, Neck Circ., Arm Length2, Belly Circ., Shoulder Circ., Inner Leg Height, Biceps Circ., Front Length, Chest Circ., Height, Hip Circ., Arm Length1, Weight

b. Dependent Variable: Waist Circumference

ANOVA[a] **Table**

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	13118.159	21	624.674	79.581	0.000[b]
	Residual	3359.608	428	7.850		
1	Total	16477.767	449			

a. Dependent Variable: Waist Circumference

b. Predictors: (Constant), Thigh Circ., Inner Arm Length, Back Neck Girth, Side Height, Chest Fall, Back Length, Shoulder Width, Back Width, Outer Leg Height, Neck Circ., Arm Length2, Belly Circ., Shoulder Circ., Inner Leg Height, Biceps Circ., Front Length, Chest Circ., Height, Hip Circ., ArmLength1, Weight

Regression Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
	Model	B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	14.152	6.541		2.164	0.031	1.295	27.009
	Height	-0.070	0.049	-0.060	-1.422	0.156	-0.166	0.027
	Weight	0.153	0.045	0.188	3.428	0.001	0.065	0.240
	Neck Circ.	0.462	0.107	0.132	4.298	0.000	0.251	0.673
	Back Neck Girth	-0.188	0.110	-0.041	-1.712	0.088	-0.404	0.028
	Shoulder Width	0.128	0.127	0.027	1.013	0.312	-0.121	0.378
	Shoulder Circ.	-0.011	0.040	-0.011	-0.286	0.775	-0.089	0.066
	Chest Circ.	0.159	0.043	0.156	3.728	0.000	0.075	0.242
	Chest Fall	0.143	0.099	0.044	1.448	0.148	-0.051	0.338
	Back Width	0.270	0.067	0.121	4.030	0.000	0.138	0.402
	Back Length	-0.103	0.066	-0.040	-1.568	0.118	-0.232	0.026
	Front Length	-0.169	0.079	-0.080	-2.154	0.032	-0.324	-0.015
	Side Height	-0.166	0.070	-0.080	-2.385	0.018	-0.303	-0.029
	Arm Length-1	-0.102	0.084	-0.057	-1.216	0.225	-0.266	0.063
	Arm Length-2	0.232	0.085	0.123	2.723	0.007	0.065	0.400
	Inner Arm Length	-0.231	0.092	-0.095	-2.506	0.013	-0.413	-0.050
	Biceps Circ.	0.376	0.089	0.162	4.242	0.000	0.202	0.550
	Belly Circ.	0.241	0.034	0.277	7.141	0.000	0.175	0.307
	Hip Circ.	0.114	0.048	0.115	2.377	0.018	0.020	0.208
	Outer Leg Height	0.085	0.034	0.089	2.507	0.013	0.018	0.151
	Inner Leg Height	-0.098	0.060	-0.062	-1.631	0.104	-0.217	0.020
	Thigh Circ.	-0.094	0.056	-0.068	-1.670	0.096	-0.204	0.017

a. Dependent Variable: Waist Circumference

Regression equation of WCM obtained with all the rest of BMs enter method:

Waist Circ. = 14.152 – 0.070 Height + 0.153 Weight + 0.462 NeckCirc. – 0.188 Back Neck Girth
+ 0.128 Shoulder Width – 0.011 Shoulder Circ. + 0.159 Chest Circ. + 0.143 ChestFall
+ 0.270 Back Width – 0.103 Back Length – 0.169 Front Length – 0.166 Side Height – 0.102 Arm Length1
+ 0.232 Arm Length2 – 0.231 Inner Arm Length + 0.376 Biceps Circ. + 0.241 Belly Circ.
+ 0.114 Hip Circ. + 0.085 Outer Leg Height – 0.098 Inner Leg Height - 0.094 Thigh Circ. (1)

Experimenting waist circumference with all the rest of body measurements using the stepwise method

WCM is conducted with all the rest of BMs' stepwise methods secondly. In this case, the dependent and the independent variables are the same as the enter method, but the method changes to stepwise here, aiming to obtain the highest r^2, consequently the Adj.r^2.

The model summary, ANOVA table, and regression coefficients stepwise method of all BMs to determine waist circumference tables are obtained but not presented here. In Model Summary, the best obtained values are in the tenth step of the model and are $r^2 = 0.786$ and Adj.$r^2 = 0.782$, which seem to be near to 0.8. Still, the adjusted regression coefficient is slightly less in the stepwise method than in the enter method, which is 0.782 and 0.786, respectively. In ANOVA, $p < 0.05$ is in every step, which indicates that regression analysis is worth conducting. In the regression coefficient list, it is each BM's effect. Equation 2 is the MMRA equation stepwise method of WCM with all the rest of the BMs.

Regression equation of WCM obtained with all the rest of the BMs stepwise method:

$$\text{Waist Circ.} = 2.958 + 0.127\,\text{Weight} + 0.325\,\text{Biceps Circ.} + 0.240\,\text{Belly Circ.} - 0.253\,\text{Side Height} + 0.152\,\text{Chest Circ.} + 0.418\,\text{Neck Circ.} + 0.230\,\text{Back Width} - 0.337\,\text{Inner Arm Length} + 0.136\,\text{Arm Length-2} + 0.101\,\text{Hip Circ.} \tag{2}$$

Experimenting waist circumference with the statistically selected effective body measurements enter method

WCM is experimented with the selected BMs enter method finally. In this case, Weight, Chest Circ., Hip Circ., Belly Circ., Biceps Circ., Thigh Circ., Shoulder Circ., Neck Circ., and Back Width are the independent variables, which are statistically selected in correlation coefficients analysis, the aim being to obtain the highest r^2, consequently the Adj.r^2.

The model summary, ANOVA table, and regression coefficients stepwise method of statistically selected effective BMs to determine waist circumference tables are obtained but not presented here. In Model Summary, the obtained r^2 is 0.756 and Adj.r^2 is 0.751, which seems to be quite high, nearly 0.8, but the adjusted regression coefficient is less in the statistical selection method than the stepwise method, which is 0.751 and 0.782, respectively. In ANOVA, $p < 0.05$ indicates that regression analysis is worth conducting. In the regression coefficient list, it is each BM's effect. Equation 3 is the MMRA equation enter method of WCM with the statistically selected effective BMs.

Regression equation of WCM obtained with our selected BMs enter method:

$$\text{Waist Circ.} = -9.205 + 0.074\,\text{Weight} + 0.189\,\text{Chest Circ.} + 0.139\,\text{Hip Circ.} + 0.226\,\text{Belly Circ.} + 0.430\,\text{Biceps Circ.} - 0.020\,\text{Thigh Circ.} - 0.047\,\text{Shoulder Circ.} + 0.412\,\text{Neck Circ.} + 0.258\,\text{Back Width} \tag{3}$$

3.5. Comparisons

MMRSs are conducted with three different points of view for each BM one by one, but only the waist circumfernce measurement is given as an example. In this case, WCM is the dependent variable, and 1) all BMs enter method, 2) all the BMs stepwise method, and 3) statistically selected BMs are the independent variables in each case. It was thought at the beginning of this research that statistical selection would be shorter, more precise, and save time and cost, or at least be comparable with the stepwise method, for both are making a selection. The enter method is to get a general idea.

The resultant Adj.r^2 is 0.786 in the enter method, (1) above paragraph; the resultant Adj.r^2 is 0.782 stepwise method, (2) above paragraph; and the resultant Adj.r^2 is 0.751 in the statistical selection method, (3) above paragraph. As seen from these results of the stepwise method, the analysis ends its work with 10 BMs which are Weight, Biceps Circ., Belly Circ., Side Height, Chest Circ., Neck Circ., Back Width, Inner Arm Length, Arm Length-2, and Hip Circ. .However, in Section 3.3., the statistically selected effective BMs are nine which are Weight, Chest Circ., Hip Circ., Belly Circ., Biceps Circ., Thigh Circ., Shoulder Circ., Neck Circ., and Back Width. The similar body measurements in both methods are Weight, Chest Circ., Hip Circ., Belly Circ., Biceps Circ., Neck Circ., and Back Width, whereas stepwise method extra includes Side Height, Inner Arm Length, and Arm Length-2; and the statistical selection method differently includes Thigh Circ. and Shoulder Circ. It can be pointed out that the difference in the extra BMs may be why the stepwise method and the statistical selection method give different results. It is also worth noting that at the beginning of this research, it was thought that it would finalize just the opposite; this was an unexpected result because it was thought that the selection of effective BMs according to their high correlation coefficients would be a shorter, more precise, and time and cost saved, but not. The highest adjusted regression coefficient is achieved in the enter method, and which is similar to the stepwise method.

The same procedure is repeated for all the BMs and the results of the three different points of view are presented in Table 9. As seen from the table, the enter method mostly results from the highest adjusted regression coefficients, but the statistical selection method could not calculate the results for four measurements which are Back Length, Back Neck Grith, Shoulder Width, and Chest Fall. This is because none of the BM pairs satisfy the $r \geq 0.5$ condition in the correlation coefficient analysis in Section 3.3. In Figure 12, the three different points of view are drawn.

Table 9. Adjusted regression coefficients of three different points of view for each body measurement

	Enter Adj.R^2	**Stepwise Adj.R^2**	**Selected Adj.R_S^2 ***
Chest Circ.	0.724	0.725	0.711
Waist Circ.	0.786	0.782	0.751
Neck Circ.	0.493	0.486	0.451
Outer Leg Height	0.608	0.596	0.496
Belly Circ.	0.703	0.703	0.669
Inner Arm Length	0.654	0.642	0.604
Hip Circ.	0.790	0.791	0.786
Arm Length-1	0.776	0.771	0.716
Arm Length-2	0.758	0.756	0.700
Shoulder Circ.	0.632	0.623	0.599
Front Length	0.643	0.634	0.388
Biceps Circ.	0.672	0.660	0.636
Back Width	0.470	0.477	0.337
Height	0.720	0.717	0.672
Weight	0.838	0.838	0.790
Thigh Circ.	0.698	0.699	0.655
Side Height	0.565	0.561	0.388
Inner Leg Height	0.651	0.645	0.634
Back Length	0.243	0.221	**
Back Neck Girth	0.150	0.122	**
Shoulder Width	0.288	0.289	**
Chest Fall	0.471	0.464	**

* These are the R^2 values found when the ones with high correlations are selected among the correlation coefficients and worked with the Enter method.
** These measurements have not been studied because they do not meet the $r \geq 0.5$ condition.

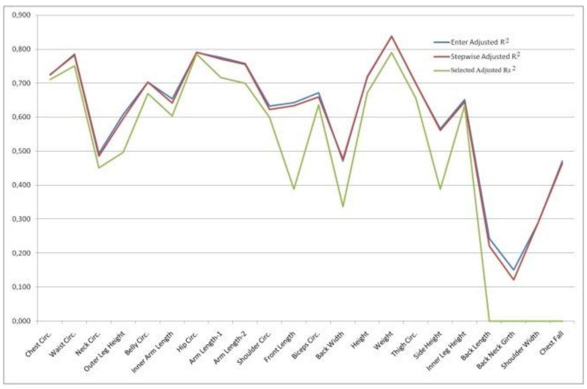


Figure 12. Drawing of adjusted regression coefficients of three different points of view for each body measurement

3.6. Validation

As mentioned at the beginning of this manuscript, there are 500 volunteers and 50 were separated for validation. The whole research was conducted with 450 volunteer BMs. Since the results of the statistical selection idea were not satisfying and couldn't reach meaningful results, no work was done for validation.

4. CONCLUSIONS

In this research, the normality assumptions of BMs are first conducted, and then a statistical selection of effective BMs to define other BMs is proposed. It was noticed in the literature that papers applying statistical methods to BMs did not mostly first check the normality of BM data and definition choices were random. Still, they were thought to have to be statistically selected for shorter, more precise, time-saving and cost-saving work. This research is done for these two purposes.

Normal distribution of BM data is proven by the five criteria of assumptions of normality which are mean, median and mode values should be equal or close to each other; histograms should look like a normal distribution curve; skewness and kurtosis coefficients should be between -1 / +1 ; normal Q-Q plot should include points above or below but close to a 45^0 diagonal line; and CV% should be less than 25%. For data to be normally distributed, it has to meet three out of five of these criteria, since the BMs of 450 volunteers met at least three or more of these criteria, it is proven that the BMs display normal distribution. Besides, boxplots and Kolmogorov-Smirnov and Shapiro-Wilk tests, which are tests not applied for normality analysis alone, were also conducted. The results did not match the assumptions of normality analysis. This research progressed by working with each BM one by one, but as an example, only the WCM is presented in this manuscript.

Correlation coefficients of each BM with the other BM are obtained and the 53 out of 231 conforming $r \geq 0.05$ condition are listed from high to low. Statistical selection is managed to specify the highly correlated pairs for each BM with the other BM to prevent random work. Multivariate multiple regression analyses are conducted for each BM with three different points of view: one BM is the dependent variable and all the other independent variables enter method, the same stepwise method, and one BM is the dependent variable and the statistically selected effective BMs independent variables enter method. Stepwise is not conducted because the proposed statistical selection already selects the variables. The Adj.r^2's of the three different points of view are compared, and the enter and stepwise methods contained high and similar results, respectively. Still, the proposed statistical selection method gave the least results and could not even be calculated for some BMs. It is assumed that this much difference in the results is because of the different variables chosen in the stepwise method but not the same in the statistical selection method. These analyses are done with each BM one by one, but as an example, only the WCM is presented in this manuscript. The resultant Adj.r^2 of WCM is 0.786 in the enter method, 0.782 in the stepwise method, 0.751 in the proposed statistical selection method, where it is seen that it is the least among the three different points of view. The proposed statistical selection method is not proven right; consequently, there was no need to validate the 50 volunteers' BM, which were separated for validation at the beginning of this research.

For future work, the proposed statistical selection method will be deeply analyzed and improved to receive shorter, more precise results and save time and cost. For further research, an arrangement must be developed for the outliers and extreme values clearly seen in boxplots. Advanced mathematical sciences like artificial neural networks, machine learning, and compound statistical methods will be implemented for body measurements.

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