

Development of an easy-to-use prediction equation for waist circumference based on BMI and body weight among a sample of Egyptian women

Nayera E. Hassan, Sahar A. El-Raufe El-Masry, Khaled H. Elwakeel, Mohamed S. El Hussieny

Department of Biological Anthropology,
Medical Research and Clinical Studies
Institute, National Research Centre, Giza,
Egypt

Correspondence to Sahar A. El-Raufe
El-Masry, PhD, Department of Biological
Anthropology, National Research Centre,
33 El-Buhouth Street, Dokki, Giza, Cairo 12622,
Egypt. Mob: 00201006606640;
e-mail: masrysa@yahoo.com

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Background/aim

Although both BMI and waist circumference (WC) estimate the level of fatness, WC may be more crucial because of its deep relationship to cardiovascular diseases. As WC is not ascertained regularly in clinical practice, this study intended to develop and substantiate an easy to use WC prognostic equation based on either BMI or body weight, appropriate for Egyptian women.

Patients and methods

A cross-sectional study included 505 Egyptian women, aged 20–60 years. Anthropometric measurements (body weight, height, and WC) were evaluated and BMI was estimated. A total of 329 women were used for construction of simplified prediction equations (learning sample) and another 176 women for assessing their legality (validation sample). Pearson's correlation coefficient, the calibration slope, and R^2 for the regression of the measured WC versus the predicted WC were used to assess execution of the equations in the validation sample.

Results

There were insignificant differences between the two samples in the measurements and BMI classification. The preponderance of the two samples were suffering from obesity (84.5 vs. 79.5%) and overweight (11.9 vs. 17.0%), respectively. The following simple equations were obtained to predict WC of Egyptian women: $WC=48.44+(1.471 \times BMI)$ or $WC=57.53+(0.487 \times \text{weight})$. There were insignificant differences in means $\pm$ SD of the measured versus predicted WC among both samples.

Conclusions

These equations precisely estimate WC. It should be helpful for medical care practitioners and public health personnel who like to detect persons and populations at risk for cardiovascular disease when the WC data are unobtainable.

Keywords:

BMI, body weight, Egyptian women, waist circumference

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Introduction

Anthropometric data gathered by self-rating surveys are usually restricted to the measurement of height and weight, which are simple, rapid, affordable, and tend to have a minor degree of reporting errors in adults. These measures are used to estimate BMI which is the most vastly used procedure to classify persons as underweight, normal weight, overweight, or obese [1]. BMI does not provide definite information on abdominal fat distribution which is well defined as an independent risk factor for cardiovascular diseases in adults and so may lead to misclassification at a time [2].

Waist circumference (WC) is an economical, noninvasive, and instructive measurement that could be included on self-reporting surveys and acting as an indicator of body adiposity and body fat distribution [1]. This procedure is of significant value in assessing those at risk for obesity-related health problems and

complications [3]. It has also been certainly associated with all-cause mortality in a number of studies [4].

There are a wide variety of techniques stated in the literature for the assessment of WC. Although close relationships exist between these evaluation sites, considerable differences obtained at these different sites have been documented [5].

Carranza Leon *et al.* [6] found that self-evaluated WC has unacceptable underestimation when used for evaluating metabolic risk. They postulated that if self-measured WC will be used; further studies on

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how to enhance the used techniques or measuring devices will be needed.

The aim of this study is to construct a simple equation accurately determining WC from either BMI or body weight to be beneficial for medical doctors and public health practitioners interesting in identifying individuals and patients at high risk for cardiovascular disease when WC data are unaffordable.

Patients and methods

Patients and study design

A simplified prediction equation to predict WC was developed and evaluated for validity in a cross-sectional study that included 505 healthy Egyptian women, who were seeking medical advice at the outpatient clinics of 'Management of visceral obesity and growth disturbance unit' in the Medical Excellence Research Centre, National Research Centre, Cairo, Egypt, between September 2017 and March 2020. The inclusion criteria stipulated that patients should be aged between 20 to 60 years. Conversely, pregnancy or lactation, taking medication known to influence body weight or composition or any clinical condition that can lead to weight loss were considered as exclusion criteria.

Ethical approval

Participated women were informed about the purpose of the study and their permission in the form of written informed consent was obtained. The protocol was approved by the Ethics Committee of the National Research Centre under approval number 16/127.

Methods

Anthropometric measurements were taken for each participated woman in the form of body weight, height, and WC following the instructions of the International Biological Program [7]. Then BMI was calculated.

Participants were weighed (barefoot and wearing light indoor clothing) to the nearest 0.1 kg using an electronic weighing scale (SECA 2730-ASTRA, Hamburg, Germany). Their height was measured to the nearest 0.5 cm using Holtain stadiometer. BMI was calculated according to the standard formula of body weight measured in kilograms divided by the square of the height in meters. Participants were then classified as normal weight, overweight, or obese according to the WHO classification [8] (normal weight BMI ≥ 18 to < 25 , overweight ≥ 25 to < 30 , obese ≥ 30).

WC was measured using a non-stretchable plastic measuring tape with a variation of 0.1 cm at the midpoint between the lower curvature of the last fixed rib and the superior curvature of the iliac crest, with the participants standing with their arms alongside the body, feet together, and abdomen relaxed [9].

Statistical analysis

Excel file contained the anthropometric measurements as well as the age, which was prepared before constructing the equation. The participated women were classified randomly; using Excel random function into two samples: learning sample (329 women) to predict the equation model and validity sample (176 women) to test the validity of the predicted equations.

Data were analyzed using the Statistical Package for the Social Sciences (SPSS/Windows, Version 18; SPSS Inc., Chicago, Illinois, USA). Normality of data was tested using the Kolmogorov–Smirnov test, and they were normally distributed. All statistical significance was set at *P* value less than 0.05.

Descriptive statistics were presented as mean $\pm$ SD for continuous variables. Student's *t* test was used for mean comparison between two samples. Pearson's correlations were used to examine the significance of linear association between measured WC (the dependent variable) and the anthropometric variables among both the learning and validation samples.

Initially, the potential to predict WC from potential predictors was examined among the learning sample by a scatter plot to detect a linear relationship with WC. Prediction equations were developed using an ordinary linear regression analysis using predictors that were found to be correlated significantly with WC. The least significant predictors were removed if the *R* was weak and the *P* value criterion was not met ($P < 0.1$).

After finalizing the derived equations with the learning sample, the model was applied to the validation sample to test external validity. Equation performance was assessed based on its explanatory power (R^2) (where *Y* is the measured WC and *X* is the predicted WC obtained using the estimation equation). Regression of the measured WC versus the predicted WC (predicted used as independent variable) and Pearson's correlation coefficient were calculated. A regression line with a slope of one and an intercept of zero indicated accurate prediction with no bias. A regression line with a slope significantly deviating from one suggested that a unit

change in WC did not correspond to a unit change in predicted WC. Student's *t* test was used for mean comparison between the measured and predicted WC, and the differences between them were calculated. Mean square error of the differences was calculated.

Results

Characteristics of the participated Egyptian women in the learning and validation samples are presented in Tables 1 and 2. There were insignificant differences between the two groups in age, all the studied anthropometric measurements (body weight, height, WC, and BMI), and BMI classification (normal weight, overweight, and obese). The mean age (41.88 ± 9.86 vs. 42.00 ± 10.41 years), BMI (36.71 ± 7.58 vs. 36.16 ± 7.27 kg/m^2), and WC (102.46 ± 13.81 vs. 101.96 ± 14.12 cm) did not differ in either the learning or validation samples (Table 1). The majority of the two samples were suffering from obesity (84.5 vs. 79.5%) and overweight (11.9 vs. 17.0%), respectively. There were insignificant differences in learning and validation samples regarding the mean and SD of the three BMI groups (Table 2).

The Pearson correlation analysis between measured WC and the potential predictors including age, weight, height, and BMI revealed highly significant strong correlations with BMI (0.808 vs. 0.878) and body weight (0.739 vs. 0.817), and highly significant weak correlations with age (0.210 vs. 0.250) in the learning and validation samples, respectively (Table 3). There were also significant weak correlations between WC and body height (0.114) in the learning sample versus insignificant weak correlations (0.083) in the validation sample. So, BMI and body weight were used to predict WC as they had highly significant strong correlations with them.

The scatter plots and linear regression analysis between the measured WC and the selected potential predictors among the learning sample revealed that BMI ($R^2=0.653$) and body weight ($R^2=0.545$) explained 65 and 55% of the changes occurred in the WC, respectively (Fig. 1). The following simplified equations were derived to predict WC of Egyptian women from either BMI or body weight:

- (1) $\text{WC} = 48.44 + (1.471 \times \text{BMI})$.
- (2) $\text{WC} = 57.53 + (0.487 \times \text{weight})$.

Table 1 Descriptive statistics for learning and validation samples

Variables	Learning sample (N=329)	Validation sample (N=176)	<i>t</i> value	<i>P</i> *
	Mean±SD	Mean±SD		
Age (years)	41.88±9.86	42.00±10.41	−0.129	0.897
Weight (kg)	92.07±20.93	90.52±20.39	0.801	0.424
Height (cm)	157.75±8.95	158.82±6.01	−1.427	0.154
BMI (kg/m ²)	36.71±7.58	36.16±7.27	0.781	0.435
WC (cm)	102.46±13.81	101.96±14.12	0.381	0.703

WC, waist circumference. **P* value more than 0.05=insignificant differences.

Table 2 Descriptive statistics for BMI among learning and validation samples

Groups	BMI				<i>t</i> value	<i>P</i> *
	Learning sample (<i>N</i> =329)		Validation sample (<i>N</i> =176)			
	<i>N</i>	Mean±SD	<i>N</i>	Mean±SD		
Overweight	39	27.61±1.32	30	27.54±1.25	0.206	0.838
Obese	278	38.59±6.63	140	38.56±6.09	0.040	0.968
Normal weight	12	22.58±1.55	6	23.13±0.995	−0.785	0.444

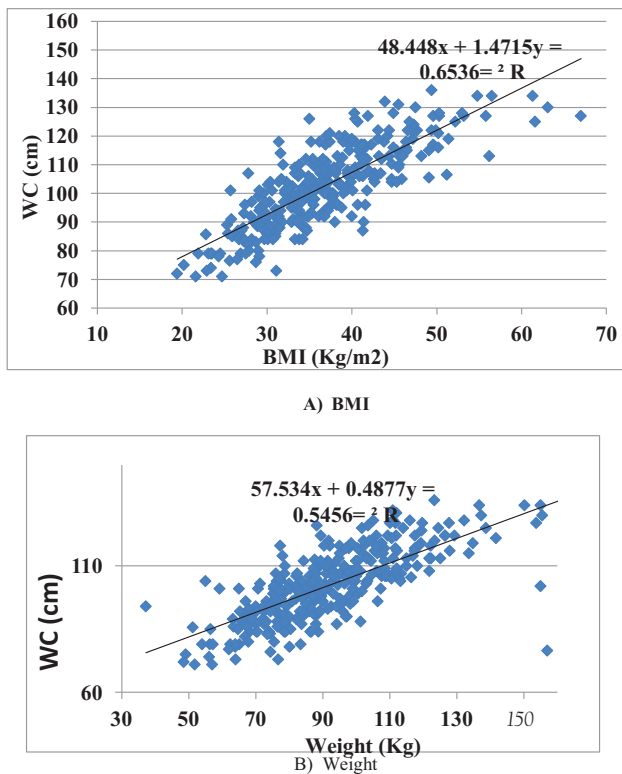
**P* value more than 0.05=insignificant differences.

Table 3 Correlation between predictors and waist circumference in learning and validation samples

Variables	WC			
	Learning sample (N=329)		Validation sample (N=176)	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
Age (years)	0.210**	0.000	0.250**	0.001
Weight (kg)	0.739**	0.000	0.817**	0.000
Height (cm)	0.114*	0.039	0.083	0.274
BMI (kg/m^2)	0.808**	0.000	0.878**	0.000

WC, waist circumference. **P* value less than 0.05=significant differences. ***P* value more than 0.05=highly significant differences.

Figure 1

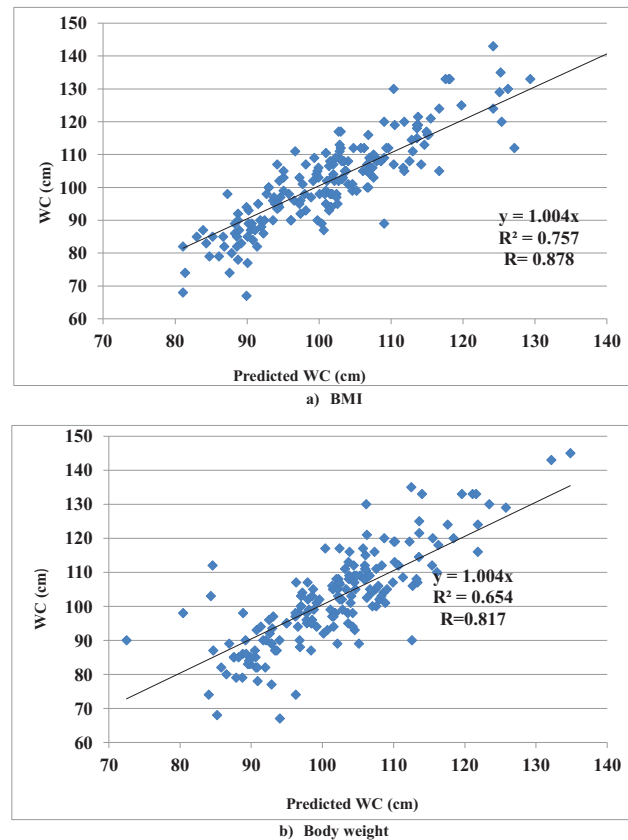


Scatter plots showing correlation between WC and predictors in the learning sample ($n=329$) where (a) BMI and (b) body weight. WC, waist circumference.

The accuracy of performance of the predicted equations was evaluated in the validation sample (Fig. 2). The regression of measured WC versus predicted values had significant slopes (measured $WC=1.004 \times [\text{predicted WC from either BMI or body weight}]$) and explained 76% ($R^2=0.757$) and 65% ($R^2=0.654$) of the variance in the predicted WC from either BMI or body weight, respectively. The slope was not significantly different from one (1.004) indicating a minimal bias. Pearson's correlation coefficient between predicted (from either BMI or body weight) and measured values of WC in the validation sample was $r=0.878$ and 0.817 , respectively.

Comparing the means $\pm$ SD of the measured and predicted WC, from either BMI or body weight, revealed insignificant differences among both learning and validation samples (Table 4). Moreover, the mean $\pm$ SD of the differences between the measured and predicted WC, from either BMI or body weight, were 0.33 ± 6.97 and 0.35 ± 8.30 , and the median was 0.08 and 0.34 cm, respectively, and the middle half of the quartile differences extends from $(-5.12 \text{ to } 4.82 \text{ cm})$ to $(-5.44 \text{ to } 5.24 \text{ cm})$, respectively (Table 5). Mean square error of the differences between the measured and the predicted WC from BMI in the validity sample

Figure 2



Calibration of prediction equation scatter plot of predicted WC from (a) BMI, (b) body weight, versus measured WC in the validation sample ($n=176$). WC, waist circumference.

Table 4 Comparisons between measured and predicted waist circumference among learning and validation samples

Variables	Learning sample (N=329) Mean $\pm$ SD	Validation sample (N=176) Mean $\pm$ SD
WC (cm)	102.46 $\pm$ 13.81	101.96 $\pm$ 14.12
Predicted WC from BMI	102.44 $\pm$ 11.16	101.64 $\pm$ 10.70
t value	0.037	0.617
P*	0.970	0.538
WC (cm)	102.46 $\pm$ 13.81	101.96 $\pm$ 14.12
Predicted WC from WT	102.37 $\pm$ 10.19	101.61 $\pm$ 9.92
t value	0.125	0.558
P*	0.900	0.577

WC, waist circumference; WT, weight. *P value more than 0.05=insignificant differences.

was 0.52 , and between the measured and the predicted WC from body weight was 0.62 , which means that the error of the current study was less than that in the Samuel *et al.* [10] model (0.75).

Discussion

Overweight and obesity are morbidity and mortality markers from metabolic and cardiovascular diseases,

Table 5 Mean±SD of the difference between measured and predicted waist circumference among validation samples

	Predicted WC from BMI	Predicted WC from WT
Mean	0.33	0.35
SD	6.97	8.30
Minimum	-22.92	-27.01
Maximum	19.63	27.44
Median	-0.076	0.338
25th quartile	-5.12	-5.44
75th quartile	4.82	-5.24
MSE	0.52	0.62

MSE, mean square error; WC, waist circumference; WT, weight.

musculoskeletal disorders, and some kinds of cancer [11]. Although increased body fat is recognized as an important causative factor, the potency of its association may depend on the method used to measure this adiposity [12].

While there are large numbers of measurement techniques, BMI is the most vastly used method for assessing overweight and obesity [2,13]. However, BMI alone is not able to classify obesity precisely; it is often utilized as it is easy to assess weight and height [13].

Measurement of WC has been advised in clinical recommendations and by the leading authority in health and societies as a cardiovascular risk indicator [5]. Its precise assessment depends on the used technique [12].

Studies display eight different sites for WC documentation, some authorized by worldwide committees and others by exploratory publications. The WHO [8] and the International Diabetes Federation [14] notify the assessment at the midpoint between the iliac crest and the lowest rib. The National Health and Medical Research Council [15], in turn, localize the superior border of the iliac crest as the anatomical site of WC assessment. Other approved sites include the minimal waist and the umbilicus. Discrepancy in the measures, even if minor, can have specific impact on abdominal obesity characterization [5].

Carranza Leon *et al.* [6] found that 57% of normal weight women, 18% of overweight women, and 23% of overweight men, who had a high-risk WC documented by the expert personnel would have been wrongly classified as low risk by self-assessment. They claimed that this is an inappropriate percentage of patients who would not be further examined if only self-assessed WC were utilized.

From this point of view, the current study targeted to construct a simple and reliable predictive equation for the measurement of WC obtained from simple anthropometric criteria. To our knowledge, a limited number of equations were reported for the estimation of WC. The majority of equations are unsuitable for precisely estimating WC among our population because some of these equations were originally developed and validated for individuals in certain populations (e.g. Western society) [16].

In the current study, BMI and body weight were used to predict WC by formulating equation in a sample of Egyptian women compared with the study documented by Samuel *et al.* [10], which was interpretable to Caucasian and African-American adult populations and not validated for other ethnic groups.

A strong point in the current study is that the majority of the two used samples were suffering from obesity (84.5 vs. 79.5%) and overweight (11.9 vs. 17.0%), respectively, compared with the Bozeman model in which the average BMI of the sample used lies in the overweight but not obese range.

The present study revealed only a minimal bias in our predicted equation as discussed in the results. Compared with the Samuel *et al.* [10] model, although the model successfully estimates WC, it tended to overstate the true WC in the lower scope of WC and underevaluate the true WC in the upper scope of WC, particularly among women. In current study, comparing the means±SD of the measured and predicted WC, from either BMI or body weight, revealed insignificant differences among both learning and validation samples. Moreover, the means±SD of the differences between the measured and predicted WC, from either BMI or body weight, were 0.33±6.97 and 0.35±8.30, respectively.

In the Samuel *et al.* [10] model, the median difference (actual WC minus predicted WC from BMI) for women is 0.11 cm, and the middle half of the differences extends from -3.84 to 3.81 cm. However, in the current study, the median difference is 0.08 cm, and the quartiles are at -5.12 and 4.82 cm. Root of the square error of the Samuel *et al.* [10] model is 0.75, while for the current study in the validity sample was 0.52, which means that the error of the current study was less than in Bozeman's model.

Conclusion

This study affords simple prediction equations of WC, particularly among overweight or obese Egyptian

women. The advantage of this equation is that it uses simple criteria (i.e. weight and BMI) that are easily obtained by health experts (e.g. medical doctors, nutritionists, dieticians), especially in clinical settings (e.g. outpatient clinics) where documentations of WC are not affordable.

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Conflicts of interest

There are no conflicts of interest.

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