Development of an Easy-to-Use Visual Aid for the Prediction of Body Fat Based on Waist Circumference and Height in Asian Chinese Adults

Christiani Jeyakumar Henry, PhD; Shalini Ponnalagu; Xinyan Bi, PhD

ARTICLE INFORMATION

Article history:
Submitted 20 July 2018
Accepted 28 February 2019
Available online 2 May 2019

Keywords:
Percentage body fat
Prediction equations
Waist circumference
Visual chart

https://doi.org/10.1016/j.jand.2019.02.017

ABSTRACT

Background Adiposity is a major risk factor for metabolic and cardiovascular diseases. Initial prediction equations to estimate adiposity are complex, requiring skinfold measurements that cannot be obtained conveniently by the general population.

Objective To develop simplified prediction equations to estimate body fat percentage (%BF) in Asian Chinese adults, evaluate the validity of the simplified %BF prediction equations, compare the simplified %BF prediction equations with an existing equation, and create visual charts to enable easy assessment of adiposity by the general public.

Design Simplified prediction equations were developed and evaluated for validity using anthropometric measurements obtained from a cross-sectional study.

Participants and setting Healthy participants with no major diseases and not taking long-term medications were recruited in a cross-sectional study conducted at Clinical Nutrition Research Centre, Singapore, between June 2014 and October 2017. A total of 439 participants were used for model building (269 women and 170 men) and another 107 participants were used for evaluating validity (62 women and 45 men).

Main outcome measures Simplified but acceptable prediction models and generation of user-friendly charts.

Statistical analyses performed Simplified sex-specific %BF prediction equations were developed using stepwise regression and the model-building dataset. The best models were selected using the Akaike information criterion. The models were further simplified and their performance was compared using the validation dataset before choosing the final prediction equations.

Results The final selected models for women and men included waist circumference and height with nonsignificant prediction bias in %BF of 0.84%±3.94% (P=0.098, Cohen's d_z=0.21) and −0.98%±3.65% (P=0.079, Cohen's d_z=0.27), respectively. The final equations were split into three height categories from which the sex-specific prediction charts were generated.

Conclusions The sex-specific prediction charts provide a good visual guide for estimating %BF using height and waist circumference values that are easy to obtain by the general public.
J Acad Nutr Diet. 2019;119(9):1533-1540.

ADIPOSITY IS AN INDEPENDENT PREDICTOR OF metabolic diseases, which makes its measurement crucial.[1,2] Body fat percentage (%BF) can be measured accurately and precisely using dual-energy x-ray absorptiometry (DEXA).[3] However, such equipment is expensive and bulky,[4] which makes it inconvenient for use in community health screening settings. Hence, prediction equations that are able to predict %BF at high accuracy have been popular. A classic example is the prediction equation developed by Durnin and Womersley in the 1970s using a sample from a white population from western Europe.[5]

Asians have different body composition than whites.[6,7] The ethnic differences in body composition led to the development of various ethnic-specific %BF prediction equations.[8] The lack of appropriate prediction equations specifically for healthy Asian Chinese adults motivated the recent development of sex-specific %BF prediction equations in Asian Chinese by Henry and colleagues.[9] These equations were built using five variables, including skinfold measurements of the biceps and triceps, waist circumference (WC), age, and height. Despite the strengths of the %BF prediction equations, challenges remained in their wider use by the general public. The challenges included difficulty in obtaining skinfold measurement, which requires appropriate equipment (ie, skinfold calipers) as well as proper training to obtain accurate measurements adhering to standard protocols,[10] and logarithmic transformation of the sum of biceps and triceps skinfold measurements, which requires numerical literacy and the use of a calculator. These challenges reduced the convenience of using the prediction equations.

To address this issue, the current study aims were to develop simplified %BF prediction equations for Asian Chinese adults that utilize anthropometric measurements that are easy to obtain without specialized instruments; evaluate the validity of the simplified %BF prediction equations using data from a cross-sectional study; compare the performance of the newly developed equations with an existing equation developed by Liu and colleagues[11]; and create graphics-based prediction charts that provide a good visual analog of the %BF values, particularly for Asian Chinese.

RESEARCH SNAPSHOT

Research Question: Can body fat percentage of healthy Asian Chinese adults be predicted using simple measurements and a visual chart?

Key Findings: Simplified sex-specific equations were developed to predict body fat percentage among Chinese adults living in Singapore. Graphics-based charts were created from the prediction equations to facilitate easy assessment of adiposity by the general public. Validation analysis revealed nonsignificant prediction bias in body fat percentage of 0.84%±3.94% (P= 0.098) in women and −0.98%±3.65% (P=0.079) in men using the new prediction equations.

MATERIALS AND METHODS

Study Design and Participants

The simplified prediction equations to predict %BF were developed and evaluated for validity using data from a cross-sectional study conducted at the Clinical Nutrition Research Centre, Singapore, between June 17, 2014, and October 20, 2017.[12] Inclusion criteria included women who were not pregnant, and men and women without a diagnosis of any major diseases and without long-term medication use. Participants were recruited through advertisements that were placed around the National University of Singapore campus, public areas, and on the Clinical Nutrition Research Centre website. A total of 439 of the enrolled participants (269 women and 170 men) with both DEXA and anthropometric measurements were used to develop the prediction equations. An additional 107 participants (62 women and 45 men) enrolled under the same study were used to evaluate the validity of the developed prediction equations. The National Healthcare Group Domain Specific Review Board, Singapore, approved the protocols for the cross-sectional study. All participants provided written and informed consent before the study commencement.

Anthropometric Measurements

Anthropometric measurements were taken in the fasting state following standard protocols[10] by research officers trained by a qualified trainer who had undertaken the 2011 International Standards for Anthropometric Assessment course.[13] WC was taken at the midpoint between the lower costal (10th rib) border and the iliac crest using a standard nonelastic measuring tape (Lufkin W606PM; Apex Tool Group). Participants were asked to breathe normally and the measurement was taken at the end of an exhalation. The quality of the WC measurement was assessed and a third measurement was taken in the case that the differences between the first two measurements was >2%. The final measurement value was taken to be the average of the duplicate or triplicate measurements. Height (in centimeters), ensuring the correct Frankfort plane (the lowest point on the inferior orbital margin; that is, orbitale, and the upper margin of the external auditory meatus; that is, tragion, form a horizontal line), was measured using a stadiometer to the nearest 0.1 cm. Weight was measured with an electronic scale (Seca GmbH) to the nearest 0.1 kg in light clothing without footwear. Height and weight measurements were done in duplicate. Each participant's %BF was measured by using DEXA (QDR 4500A, fan-beam densitometer, Hologic).

Statistical Analysis

Sex-specific prediction equations were generated with simple measurements; that is, WC, weight, height, body mass index (BMI), waist-to-height ratio, and age. Because there was a nonlinear relationship between weight and %BF among women, weight was log transformed for the women. Variable selection (including height, age, WC, and weight) was done using stepwise regression methods. Models were compared using the Akaike information criterion (AIC) a measure to compare the fit of related models for a given dataset. Smaller AIC values indicated a better model fit. Hence the model with the smallest AIC was chosen as one of the plausible models.[14]

For the purpose of comparison, variable selection using BMI and age as well as waist-to-height ratio and age was also done separately to obtain two more plausible models (Step 1 of the model-building process). The three plausible models (Table 1 and Table 2) were compared based on their predicted R^2 and standard error of estimate (SEE) obtained from the model-building dataset. Predicted R^2 indicated the predictive performance of the models in a new dataset that has different set of participants, not included in the model-building set. Higher predicted R^2 and smaller SEE were indications of better model performance. A single model was then selected for further simplification (Step 2). The simplified model was defined to be one that had at least two anthropometric variables that could be easily obtained.

Mean absolute percentage error and prediction bias of the models were used to compare the performance of the predictive models in Step 2 of the model-building process using the validation dataset. Mean absolute percentage error was calculated using the formula as follows:

Mean absolute percentage error $=\left\{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{|observed_i-predicted_i|}{observed_i}\right)\right\}\times 100\%$; where i represents the individuals in the sample and n is the total number of people in the sample under consideration.

Prediction bias referred to the mean difference between the observed and predicted values. The smaller the

Table 1. Details of the model selection process for women using the model-building data set (n=269); data were obtained from a cross-sectional study on Asian Chinese conducted in Singapore between June 17, 2014, and October 20, 2017[a]

Step	Models and independent variables	Predicted R^2	AIC	SEE	Adjusted R^2	Mean absolute percentage error[bc]	Prediction bias[b] (%±standard deviation)
1	Model 1: Age, body mass index	0.54	713.5	3.8	—	—	—
	Model 2: Age, waist-to-height ratio, weight[d]	0.57	699.8	3.7	—	—	—
	Model 3[e]: A circumference, height, weight[d]	0.57	695.8	3.6	0.58	9.2	0.73±3.81
2	Model 3a: Age, waist circumference, height	0.55	—	3.7	0.56	9.5	0.94±3.87
	Model 3b: waist circumference, height	0.54	—	3.8	0.54	9.8	0.84±3.94
	Liu model[f]: Body mass index, waist circumference, age, waist circumference^2	—	—	—	—	18.0	−6.24±3.94***

[a]Predicted R^2, adjusted R^2, standard error of estimate (SEE), and Akaike information criterion (AIC) were obtained using the model building dataset (n=269).
[b]Mean absolute percentage error and prediction bias was obtained using the validation dataset (n=62).
[c]Mean absolute percentage error$=\left\{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{|observed_i - predicted_i|}{observed_i}\right)\right\}\times 100\%$, where i represents the individuals in the sample; n is the total number of people in the sample under consideration. The smaller the value of mean absolute percentage error, the more accurate the model estimates.
[d]Log transformed.
[e]Model 3 was the final selected model in terms of the model with the best Predicted R^2, lowest AIC, and SEE. This model was further simplified in Step 2.
[f]Liu and colleagues model[11] for women: body fat %=−22.46354525+0.32551474×body mass index+0.87135268×waist circumference+0.00319864×age×body mass index−0.00408430×waist circumference^2.
***P<0.001.

difference, the better the predictive model fits the data. Hence, the model with the smallest mean absolute percentage error was chosen as the best fitting model.

Using the validation dataset, the final simplified predictive equations selected in Step 2 were evaluated for bias using a paired sample t test and deviation from the line of identity (a test for the slope=1 and the intercept=0). For

Table 2. Details of the model selection process for men using the model-building data set (n=170); data were obtained from a cross-sectional study on Asian Chinese conducted in Singapore between June 17, 2014, and October 20, 2017[a]

Step	Models and independent variables	Predicted R^2	AIC	SEE	Adjusted R^2	Mean absolute percentage error[bc]	Prediction bias[b] (%)±standard deviation
1	Model 1: Age, body mass index	0.49	478.0	4.0	—	—	—
	Model 2: Waist-to-height ratio	0.61	431.1	3.5	—	—	—
	Model 3[d]: age, waist circumference, height	0.62	428.5	3.5	0.63	12.4	−1.0±3.66
2	Model 3a: Waist circumference, height	0.62	—	3.5	0.63	12.3	−0.98±3.65
	Liu model[e]: Body mass index, waist circumference, waist circumference^2	—	—	—	—	22.5	−5.94±3.82***

[a]Predicted R^2, adjusted R^2, standard error of estimate (SEE), and Akaike information criterion (AIC) were obtained using the model building dataset (n=170).
[b]Mean absolute percentage error and prediction bias was obtained using the validation dataset (n=45).
[c]Mean absolute percentage error$=\left\{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{|observed_i - predicted_i|}{observed_i}\right)\right\}\times 100\%$, where i represents the individuals in the sample; n is the total number of people in the sample under consideration. The smaller the value of mean absolute percentage error, the more accurate the model estimates.
[d]Model 3 was the final selected model in terms of the model with the best Predicted R^2, lowest AIC and SEE. This model was further simplified in Step 2.
[e]Liu and colleagues model[11] for males: Body fat %=−41.92778773+0.33718996×body mass index+0.99622038×waist circumference−0.00403169×waist circumference^2.
***P<0.001.

the deviation from the line of identity assessment, the predicted values were used as the dependent variable and the actual %BF measured with DEXA was used as the independent variable. A statistically significant result would indicate there was fixed or proportional bias in the predictive model. To indicate the size of the standardized difference, Cohen's d_z for the effect size of a paired sample t test was also reported. The accuracy and performance of the new chosen simplified prediction equations were also cross-validated in an independent validation dataset as well as compared with the prediction equations developed by Liu and colleagues.[11]

The final models were further transformed for simpler translation into a chart that could be easily read by the general public. The value of the standardized coefficients was used as a guide to decide the cutoff values for the variables to be categorized (ie, height) in the graphics-based prediction chart.

The Mann-Whitney test was used to compare the characteristics of participants in the model-building dataset with participants in the validation dataset. The proportion of married participants was compared using a two-sample test for the equality of proportions. All analyses were performed using Statistical Software for the Social Sciences[15] and R Statistical Software.[16] Data are reported as mean±standard deviation or n and percent. All statistical tests in this study were set at a significance level $<$0.05.

RESULTS

Table 3 summarizes the characteristics of the participants recruited in the study. There were no statistically significant differences in the participant characteristics between the model validation and model-building datasets (P>0.05). Model development was performed separately for each sex using this dataset. Model 3 was chosen to be further reduced (Table 1 and Table 2) because it had the highest predicted R^2 and lowest SEE for both sexes compared with models 1 and 2.

In women, the potential model chosen for simplification included age, WC, height, and weight (log transformed) as predictors. Because weight and WC were highly correlated with each other, models with and without the transformed weight were compared while keeping age, WC, and height in the model (Step 2 of model selection). Evaluation of validity for both models showed that after removing weight, the mean absolute percentage error decreased by 0.3, but the prediction bias was still $<$1% and the SEE had increased by only 0.1. Thus, removing weight made minimal changes in model validity, but produced a more parsimonious model

Table 3. Description of the study participants used in model-building (n=439) and validation datasets (n=107); data were obtained from a cross-sectional study on Asian Chinese conducted in Singapore between June 17, 2014, and October 20, 2017

Characteristic[a]	Model-Building Dataset: Women (n=269)	Model-Building Dataset: Men (n=170)
	←mean±standard deviation (range)→	
Age (y)	38.0±14.5 (21.0-68.6)	38.4±14.5 (21.0-69.2)
Height (cm)	159.5±5.8 (144-175)	171.2±5.8 (157-188)
Weight (kg)	55.0±9.2 (34.5-88.3)	68.5±9.9 (46.0-111.0)
Waist circumference (cm)	69.7±7.8 (52.8-99.1)	79.1±8.6 (62.1-109.9)
Body fat from DEXA[b] (%)	34.8±5.6 (21.9-52.7)	24.2±5.7 (11.8-37.2)
Body mass index	21.6±3.3 (16.2-33.2)	23.4±3.2 (16.3-37.5)
	←n (%)→	
Married	87 (32.3)	75 (44.1)
	Validation Dataset	
	Women (n=62)	**Men (n=45)**
	←mean±standard deviation (range)→	
Age (y)	40.6±14.6 (21-74)	37.8±15.4 (22.0-74.0)
Height (cm)	160.3±5.2 (148-177)	172.7±7.4 (157-185)
Weight (kg)	57.1±11.8 (39-104)	70.7±10.7 (51.6-94.5)
Waist circumference (cm)	72.2±9.0 (55-103)	81.2±7.7 (68.0-98.5)
Body fat from DEXA (%)	35.1±6.1 (23-49)	26.1±5.6 (14.8-38.1)
Body mass index	22.1±3.9 (16-38)	23.6±2.7 (19.0-30.6)
	←n (%)→	
Married	24 (38.7)	14 (31.1)

[a]There was no significant difference in the participant characteristics between the model-building and validation dataset. Comparison was made using Mann-Whitney test. Comparison of the proportion of married individuals in the model building dataset and validation dataset was done using two-sample test for equality of proportions.
[b]DEXA=dual energy x-ray absorptiometry.

(Table 1). Similarly, removing age resulted in a simpler model consisting of only WC and height. The model performed equally well compared with the models inclusive of age. The equation chosen for women was:

$$\text{body fat (\%) for women} = 28.33 + [0.52 \times \text{WC (in centimeters)}] - [0.19 \times \text{height (in centimeters)}]$$

In men, predictive models with and without age, but with both WC and height performed equally well in the validation dataset with similar mean absolute percentage error (smaller values preferred), prediction bias, and SEE values. Thus, for simplicity, the model equation chosen for men was:

$$\text{body fat (\%) for men} = 10.14 + [0.52 \times \text{WC (in centimeters)}] - [0.16 \times \text{height (in centimeters)}]$$

The accuracy and performance of the present simplified prediction equations were cross-validated in an independent validation dataset as well as compared with the equations developed by Liu and colleagues.[11] The present equations produced nonsignificant prediction bias in %BF estimation of 0.84%±3.94% in women and −0.98%±3.65% in men. In contrast, the equations developed by Liu and colleagues[11] resulted in prediction bias of −6.24%±3.94% in women and −5.94%±3.82% in men. The present equations have smaller mean absolute percentage error (9.8% in women and 12.3% in men) compared with the equations developed by Liu and colleagues[11] (18.0% in women and 22.5% in men). However, the line of identity obtained using the present equations as well as that of the Liu and colleagues[11] had significant intercepts and slopes for both sexes (Table 4), indicating the new equations and the Liu equations may have fixed or proportional bias.

Table 4. Evaluation of the validity of the newly developed simplified prediction equations and Liu and colleagues[11] predictive equations using 107 datasets (62 women and 45 men) from a cross-sectional study on Asian Chinese conducted in Singapore between June 17, 2014, and October 20, 2017

	Model	
Sex	**Liu and colleagues[11]**	**New Simplified[a]**
	Estimated intercept of line of identity[b] (95% CI)	
Female	10.75*** (6.81-14.69)	16.12*** (11.73-20.51)
	Estimated slope of line of identity[b] (95% CI)	
	0.52*** (0.41-0.63)	0.57*** (0.44-0.69)
	Estimated intercept of line of identity[b] (95% CI)	
Male	8.49*** (5.17-11.80)	11.56*** (7.92-15.20)
	Estimated slope of line of identity[b] (95% CI)	
	0.45*** (0.32-0.57)	0.52*** (0.38-0.66)

[a]Model for men: body fat (%)=10.14+[0.52×waist circumference (in centimeters)]−[0.16×height (in centimeters)] and model for women: body fat (%)=28.33+[0.52×waist circumference (in centimeters)]−[0.19×height (in centimeters)].
[b]Line of identity method was used to evaluate the validity of the models with the predicted body fat percentage values as the dependent variable and the actual measured body fat percentage values as the independent variable.
***$P<0.001$.

Because the standardized coefficients of the height in the simplified prediction equations were lower than WC in both sexes, the range of height values were split into three height groups of 10 cm range each. For women the three height groups were 144 to 153 cm, 154 to 163 cm, and 164 to 173 cm. For men, the three height groups were 157 to 166 cm, 167 to 176, and 177 to 186 cm. Regression equations with height as a categorical variable with three levels were created for each sex from which sex-specific prediction charts were developed (see the Figure).

Validating the models with height as a categorical variable using the validation dataset resulted in similar performance as the simplified prediction equations in each sex. There was nonsignificant prediction bias of 0.90%±3.99% and −0.98%±3.65% in women and men, respectively. Mean absolute percentage error of these new models was 9.9% and 12.3% in women and men, respectively.

The average height of Singaporean Chinese women and men is about 160 cm and 172 cm, respectively. Although the height variable was being bounded into 10 cm categories, data from a few participants were dropped from the data set without loss of generality.[17] There were a few extreme heights for men and women that had to be removed to prevent their influence on the translation of the new equations into the visual aid charts. Two female participants (height of 175 cm each) and one male participant (height of 188 cm) in the original model-building dataset were removed so that prediction equations with three levels for height could be developed. The final models selected in Step 2 of the model-building process were redone using the model-building dataset without the extreme values and were also evaluated for validity using the validation dataset without the extreme values. The redeveloped models and the models with three levels of height were consistent in the final comparisons. The model performances for the original and participant reduced models were similar (Table 5).

DISCUSSION

In many remote regions of the world where access to computers and calculators are limited, the need for a simple visual chart to predict %BF from anthropometric measures is important. With this in mind, an easy-to-use chart for global use has been developed in this study. Based on a review of currently published predictive equations to estimate %BF using anthropometric measurements, the new, easy-to-use chart developed in this study is a much simpler and more accurate model.

Asians have different body composition compared with whites because Asians have a higher tendency to deposit fat in the abdominal area.[18,19] Thus, the inclusion of WC in the %BF equations was essential for calculating more accurate values for the easy-to-use visual aid. In the current study and a study by Henry and colleagues,[9] models for both sexes with WC performed better compared with models without WC. Skinfold measurements have been important primary variables in the development of %BF prediction equations for Asian Chinese,[5,8,9,20-22] but skinfold measurements are difficult to obtain without the proper training and equipment. In contrast, the use of simpler anthropometric measurements,

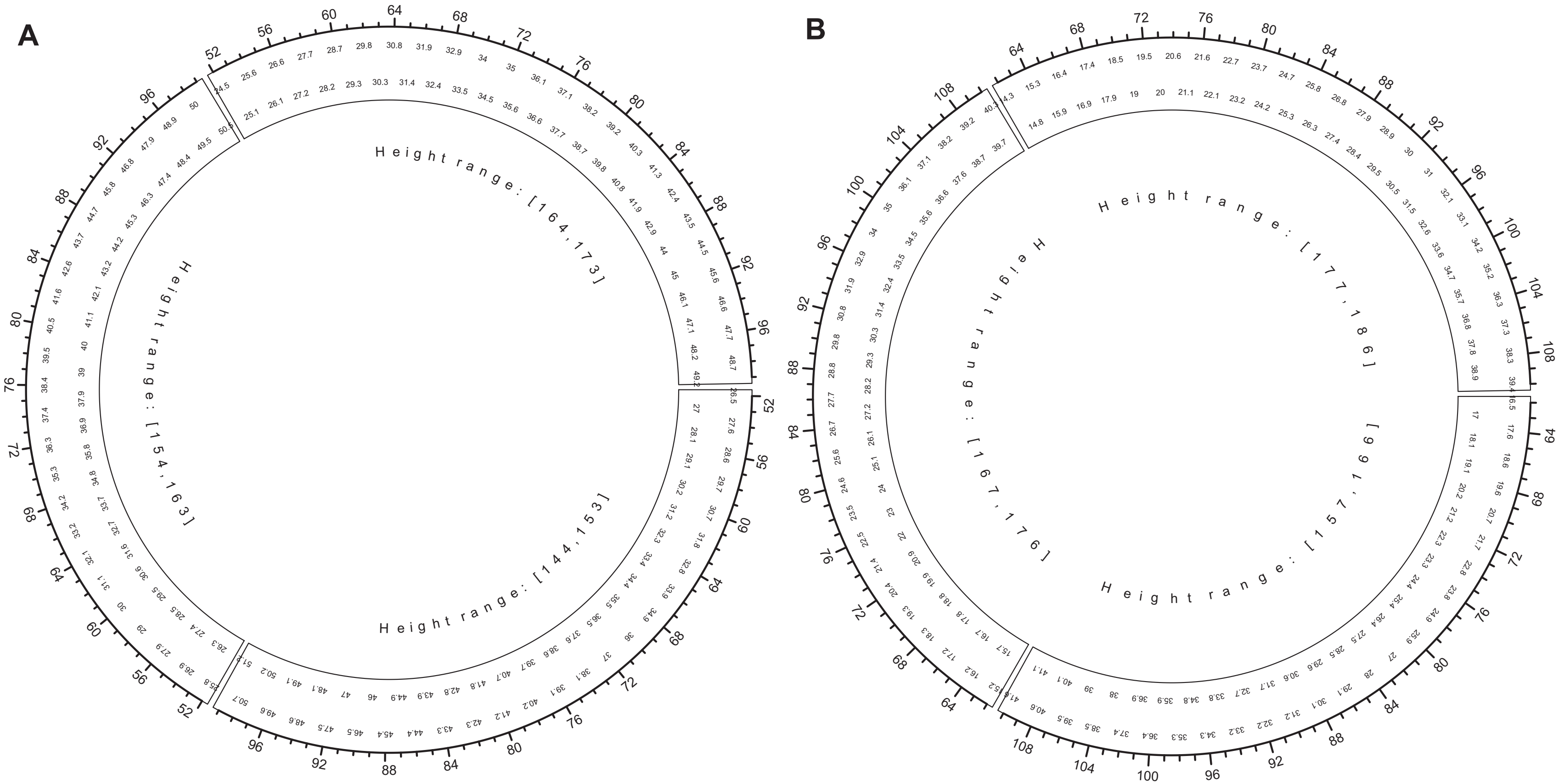

Figure. (A) Prediction chart for Asian Chinese women. The three segments represent the height categories: 144 to 153 cm, 154 to 163 cm, and 164 to 173 cm. The scale on the outer circumference of the circle represents the waist circumference ranging from 52 to 99 cm. The values within the sector represent the corresponding estimated percentage body fat values. The prediction bias of the chart is 0.90%±3.99%. (A dial will be added at the center in the actual chart to be used.) (B) Prediction chart for Asian Chinese men. The three segments represent the height categories: 157 to 166 cm, 167 to 176 cm, and 177 to 186 cm. The scale on the outer circumference of the circle represents the waist circumference ranging from 62 to 110 cm. The values within the sector represent the corresponding estimated percentage body fat values. The prediction bias of the chart is −0.98%±3.65%. (A dial will be added at the center in the actual chart to be used.)

Table 5. Performance of the models developed using the restricted model-building dataset (267 women, 169 men) and evaluated for validity in the restricted validation sample (61 women, 45 men); data were obtained from a cross-sectional study on Asian Chinese conducted in Singapore between June 17, 2014, and October 20, 2017; the performance was compared with height as a continuous variable and as a variable with three categories

Sex	Model	Mean absolute percentage error[a]	Prediction bias (%)
			mean±standard deviation
Female (n=61)[b]	Model: Waist circumference, height categories[c]	9.87	0.90±3.99
	Model: Waist circumference, height	9.59	0.79±3.90
Male (n=45)[d]	Model: Waist circumference, height categories[e]	12.34	−0.98±3.65
	Model: Waist circumference, height	12.31	−0.99±3.65

[a]Mean absolute percentage error $=\left\{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{|observed_i - predicted_i|}{observed_i}\right)\right\}\times 100\%$, where *i* represents the individuals in the sample; *n* is the total number of people in the sample under consideration. The smaller the value of mean absolute percentage error, the better it is.

[b]Women of height 175 cm in the model-building dataset as well as height 177 cm in the validation dataset were removed.

[c]Height categories include 144 to 153 cm, 154 to 163 cm, and 164 to 173 cm.

[d]Men of height 188 cm in the model-building dataset were removed.

[e]Height categories include 157 to 166 cm, 167 to 176 cm, and 177 to 186 cm.

such as height, WC, and weight, do not require specialized equipment and the %BF can be more easily calculated.

Simple anthropometric measurements (eg, BMI, WC, and age) were also used by Liu and colleagues[11] to develop %BF prediction equations for Chinese adults. The results from the current study and the Liu and colleagues[11] study showed potential bias in the prediction models. However, compared with Liu and colleagues,[11] the current study had much smaller nonsignificant prediction bias in both sexes for the estimated %BF. The current study %BF estimation for prediction bias was 0.84%±3.94% in women and −0.98%±3.65% in men. In contrast, the estimates for the prediction bias from the Liu equations were −6.24%±3.94% in women and −5.94%±3.82% in men ($P<0.001$ for both sexes). Evaluation of validity using the line of identity method showed that there was a statistically significant nonzero intercept and significant slope that is not equal to 1 in both the newly developed simplified equations and the equations developed by Liu and colleagues.[11] The results indicate that there is no one-to-one relationship between the predicted %BF values and the actual observed values as desired. The significant deviations from zero and one indicated potential bias in the prediction models.

There were modest differences between the characteristics of the participants in the validation dataset of the current study and the model-building dataset of Liu and colleagues,[11] which could explain the predictive performance of the Liu model. The mean %BF of the participants in the validation dataset of our study (Table 3) was higher than those used in the model-building dataset of Liu and colleagues.[11] Furthermore, the participants in the current validation dataset were younger with smaller WC than participants used for model building by Liu and colleagues.[11] These differences in characteristics were likely reasons for why the Liu and colleagues model did not have comparable predictive performance to the new model.[11]

The estimates from the current study equations had nonsignificant overestimation and underestimation, around 1% for both sexes (for women $P=0.098$, Cohen's $d_z=0.21$ and for men $P=0.079$, Cohen's $d_z=0.27$). This modest bias of 1% using the newly developed model can be compared with the large significant ($P<0.001$ in both sexes) bias of about 6% in both sexes (women: −6.24%±3.94% and men: −5.94%±3.82%) from the Liu and colleagues[11] model. The current estimates also had smaller mean absolute percentage errors (12.3% in men and 9.8% in women) compared with Liu and colleagues[11] (22.5% in men and 18.0% in women).

The current %BF equations for the visual aid charts were further enhanced by classifying height into equal, sex-specific categories based on the standardized beta coefficient values of height and WC. It was also reasonable to categorize the height variable into intervals of equal width because changes in WC were more likely to occur than changes in height. The results from models with three levels also showed nonsignificant prediction bias of <1% for both sexes. The graphics-based chart produced from simplified equations are a viable option to obtain %BF in adults.

There are a number of strengths in this study. The first was the development of easy to use %BF prediction charts that gives a quick prediction without requiring specialized instruments such as a skinfold caliper. The second strength of this study is the large sample size used to develop the simplified prediction equations.

There are a number of limitations in this study as well. Firstly, the prediction chart has a lower accuracy compared with the use of the prediction equations involving skinfold measurement. However, the benefits of acceptable, easy to obtain estimates for %BF outweighed the small loss in estimated accuracy. Secondly, the prediction chart was limited to healthy Asian Chinese sample in Singapore and may not be applicable to other adult Asian Chinese populations.

CONCLUSIONS

A simplified sex-specific prediction equation of %BF for the Asian Chinese has been developed along with a quick reference graphical prediction chart. The benefit of this equation is the use of measurements that are easily obtained by the general public. More research is warranted to validate its applicability in a larger number of Chinese adults living around the world.

References

1. De Lorenzo A, Bianchi A, Maroni P, et al. Adiposity rather than BMI determines metabolic risk. *Int J Cardiol*. 2013;166(1):111-117.
2. de Oliveira CC, Roriz AKC, Ramos LB, Neto MG. Indicators of adiposity predictors of metabolic syndrome in the elderly. *Ann Nutr Metab*. 2017;70(1):9-15.
3. Mazess RB, Barden HS, Bisek JP, Hanson J. Dual-energy x-ray absorptiometry for total-body and regional bone-mineral and soft-tissue composition. *Am J Clin Nutr*. 1990;51(6):1106-1112.
4. Wells JC, Fewtrell MS. Measuring body composition. *Arch Dis Child*. 2006;91(7):612-617.
5. Durnin JV, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: Measurements on 481 men and women aged from 16 to 72 years. *Br J Nutr*. 1974;32(01):77-97.
6. He Q, Horlick M, Thornton J, et al. Sex and race differences in fat distribution among Asian, African-American, and Caucasian prepubertal children. *J Clin Endocrinol Metab*. 2002;87(5):2164-2170.
7. Haldar S, Chia SC, Henry CJ. Body composition in Asians and Caucasians: Comparative analyses and influences on cardiometabolic outcomes. *Adv Food Nutr Res*. 2015;75:97-154.
8. Davidson LE, Wang J, Thornton JC, et al. Predicting fat percent by skinfolds in racial groups: Durnin and Womersley revisited. *Med Sci Sports Exerc*. 2011;43(3):542.
9. Henry CJ, Shalini D, Ponnalagu O, Bi X, Tan S-Y. New equations to predict body fat in Asian-Chinese adults using age, height, skinfold thickness, and waist circumference. *J Acad Nutr Diet*. 2018;118(7):1263-1269.
10. Lohman TG, Roche AF, Martorell R. *Anthropometric Standardization Reference Manual*. Champaign, IL: Human Kinetics Books; 1988.
11. Liu X, Sun Q, Sun L, et al. The development and validation of new equations for estimating body fat percentage among Chinese men and women. *Br J Nutr*. 2015;113(9):1365-1372.
12. Bi X, Loo YT, Henry CJ. Body fat measurements in Singaporean adults using four methods. *Nutrients*. 2018;10(3):303.
13. Arthur Stewart MM-J, Olds T, de Ridder H. *International Standards for Anthropometric Assessment*. New Zealand: The International Society For the Advancement of Kinanthropometry; 2011.
14. Shmueli G. To explain or to predict? *Stat Sci*. 2010;25(3):289-310.
15. *SPSS version 24*. Armonk, NY: IBM-SPSS Corp; 2016.
16. R: A language and environment for statistical computing version 3.3. 2. Vienna, Austria: R Foundation for Statistical Computing; 2016.
17. Chuan TK, Hartono M, Kumar N. Anthropometry of the Singaporean and Indonesian populations. *Int J Ind Ergonomics*. 2010;40(6):757-766.
18. Lim U, Ernst T, Buchthal S, et al. Asian women have greater abdominal and visceral adiposity than Caucasian women with similar body mass index. *Nutr Diabet*. 2011;1(5):e6.
19. Wulan S, Westerterp K, Plasqui G. Ethnic differences in body composition and the associated metabolic profile: A comparative study between Asians and Caucasians. *Maturitas*. 2010;65(4):315-319.
20. Chan D, Li A, So H, Yin J, Nelson E. New skinfold-thickness equation for predicting percentage body fat in Chinese obese children. *HK J Paediatr*. 2009;14:96-102.
21. Ball S, Swan PD, Desimone R. Comparison of anthropometry to dual energy X-ray absorptiometry: A new prediction equation for women. *Res Q Exerc Sport*. 2004;75(3):248-258.
22. Kwok T, Woo J, Lau E. Prediction of body fat by anthropometry in older Chinese people. *Obesity*. 2001;9(2):97-101.

AUTHOR INFORMATION

C. J. Henry is director, Clinical Nutrition Research Centre, Singapore Institute for Clinical Sciences (SICS), Agency for Science, Technology and Research (A*STAR) and National University Health System, Singapore, and a professor, Department of Biochemistry, Yong Loo Lin School of Medicine, National University of Singapore, Singapore. S. Ponnalagu is a statistician and X. Bi is a senior research fellow, Clinical Nutrition Research Centre, Singapore Institute for Clinical Sciences (SICS), Agency for Science, Technology and Research (A*STAR) and National University Health System, Singapore.

Address correspondence to: Christiani Jeyakumar Henry, PhD, Centre for Translational Medicine, Yong Loo Lin School of Medicine, 14 Medical Dr, #07-02, MD 6 Bldg, Singapore 117599. E-mail: Jeya_Henry@sics.a-star.edu.sg

STATEMENT OF POTENTIAL CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

FUNDING/SUPPORT

The research reported in this article was funded by the Singapore Agency for Science, Technology and Research (grant no. SPF/003).

ACKNOWLEDGEMENTS

The authors thank Dr Agnes Tey and Yi Ting Loo for assisting in data collection for the study used in equation development and validation. The authors also thank the primary funder, Singapore Agency for Science, Technology and Research, for funding this study.

AUTHOR CONTRIBUTIONS

C. J. Henry designed the study. X. Bi conducted the study used in equation development and validation. S. Ponnalagu performed statistical analysis. C. J. Henry, S. Ponnalagu, and X. Bi interpreted the results and wrote the manuscript.