Prediction of percentage body fat from anthropometric measurements: comparison of New Zealand European and Polynesian young women

Elaine C Rush, Lindsay D Plank, Manaia S Lau lu, and Stewart M Robinson

ABSTRACT The prediction of total body fat from simple anthropometric measurements was examined in 42 white (New Zealand European) and 40 Polynesian women aged 18–27 y. Percentage body fat (%BF) was determined from measurements of total body water (TBW) by 18O dilution. Mean (± SD) body mass index (BMI; in kg/m²) averaged 29.2 ± 7.9 (range: 16.5–48.0) for the New Zealand European group and 31.2 ± 7.9 (range: 19.8–51.8) for the Polynesian group. %BF calculated from TBW was similar in the two groups (40.5 ± 9.9% for the New Zealand European compared with 39.1 ± 7.5% for the Polynesian group). BMI was significantly correlated with height in the Polynesian group but not in the New Zealand European group. The relation between BMI and %BF was curvilinear for both groups. At a fixed %BF, BMI was higher in the Polynesian group than in the New Zealand European group. A BMI of 30 for the New Zealand European group corresponded to a BMI of 34 for the Polynesian group at an equivalent %BF (42%). Prediction equations for %BF developed from skinfold thicknesses or girth measurements were ethnicity dependent. We conclude that the BMI criterion for obesity in whites requires revision for use in Polynesians. Am J Clin Nutr 1997;66:2–7.

KEY WORDS Fat, anthropometry, body mass index, fat distribution, ethnicity, total body water, women, Polynesians, prediction equations, whites, New Zealand Europeans

INTRODUCTION

Excess body fat is associated with chronic diseases such as hypertension, non-insulin-dependent diabetes mellitus, strokes, and myocardial ischemia (1). Polynesians are at higher risk of developing these obesity-related diseases than are New Zealand and Europeans (2). Simple anthropometric measures for assessing body fat or obesity that have been developed for white populations may not be applicable to Polynesians (3). In particular, the body mass index [BMI; weight(kg)/height(m)²] is widely used as a measure of obesity with 20–25 being categorized as normal and a value > 30 as obese (4, 5). The BMI relation to obesity and these reference values were determined by using white subjects and it has been suggested by others (6) that at a given BMI Polynesian men and women are leaner than New Zealand Europeans.

The purpose of the present study was to investigate the relation between percentage body fat (%BF), as derived from measurements of total body water (TBW), and BMI in Polynesian and New Zealand European women over a wide range of body fat content. The extent to which this relation may be influenced by ethnic differences in fat distribution was also examined through measurements of skinfold thicknesses and trunk girths.

SUBJECTS AND METHODS

Subjects

The study was approved by the University of Auckland Human Subjects Ethics Committee and the Auckland Institute of Technology Ethics Committee. Study subjects were 82 healthy female volunteers aged between 18 and 27 y recruited by personal contact and advertisement. All subjects gave their free and informed consent. Measured resting blood pressure and fasting blood glucose were within normal limits for all subjects, ie, diastolic blood pressure was not > 90 mm Hg and fasting blood glucose concentration was < 5.7 mmol/L. Forty-two identified themselves as New Zealand European, 40 as Polynesian (22 Samoan, 12 Maori, 3 Tongan, 2 Niuean, and 1 Cook Islander). Twenty-one and 20 in these respective ethnic groups had a BMI > 30. Average age (± SD) for the New Zealand European group was 22.5 ± 2.4 y (range: 18–27 y) and for the Polynesian group was 21.7 ± 2.0 y (range: 18–25 y).

Study protocol

Subjects reported to the laboratory at 0900 after an overnight fast. Resting blood pressure and blood glucose concentration were measured. Standing height was measured to 0.1 cm with a stadiometer. Weight was measured to 0.025 kg on a beam balance with the subject in minimal clothing. Skinfold thicknesses and girth measurements were obtained and TBW was

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Supported by grants from the Auckland Institute of Technology Contestable Research Fund and the Health Research Council of New Zealand.

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Received September 12, 1996.

Accepted for publication February 11, 1997.
determined by dilution of $^{18}$O-labeled water. The latter determination required subjects to return to the laboratory 7 and 14 d later to provide urine samples. All measurements on all subjects were made by the same investigator (ECR).

**Anthropometric measurements**

Skinfold thickness was measured at biceps, triceps, subscapular, and suprailiac sites with Harpenden calipers by using the recommendations of Keys and Brozek (7). All measurements were made on the right side of the body and repeated at each site until three measurements within 5 mm of each other were obtained. Body density was calculated from the sum of the average skinfold thicknesses at each site by using the equations of Durnin and Womersley (8) developed for 16–19- and 20–29-y old women.

Anatomical landmarks as used by Tran and Weltman (9) were used to obtain the three girths used in their generalized equation for predicting body density of women from girth measurements. Two girths are taken around the abdomen. The first (abdomen 1) is defined laterally as midway between the lowest portion of the rib cage and the iliac crest and anteriorly midway between the inferior border of the xyphoid process of the sternum and the umbilicus. The second (abdomen 2) is defined laterally at the level of the iliac crest and anteriorly at the umbilicus. The third girth (hip) is defined anteriorly at the level of the symphysis pubis and posteriorly at the maximal protrusion of the gluteal muscles. A nonstretch tape was used with a device to ensure that constant tension was applied. Measurements were to the nearest 1 mm. The equation developed by Tran and Weltman (9) was used to predict body density from girth measurements, height, and age.

The following equation was used to convert density to %BF (10):

$$\%BF = \left(\frac{4.971}{\text{density}} - 4.519\right) \times 100$$

although no significant difference arose through use of the Siri equation (11).

**Total body fat from isotopic measurement of TBW**

After a baseline urine sample was collected, each subject ingested $\text{H}_2^{18}$O (10.16 atom percent; Enritech Enrichment Technologies, Rehovot, Israel) as a dose of 1.5 g/kg fat-free mass, as assessed from girth measurements, followed by two 50-mL washes of the container with tap water. Four and 5 h postdose the subjects emptied their bladders and 50-mL samples were stored in a freezer. The subjects collected timed urine samples 2 and 5 d later and on days 7 and 14 reported to the laboratory for sample collection.

The $^{18}$O isotope enrichments were determined on an isotope-ratio mass spectrometer (Tracer Mass, Europa Scientific, Cheshire, United Kingdom). The $^{18}$O dilution space was calculated by using the multipoint slope-intercept method as described by Coward (12). The zero-time intercept was obtained by determining the linear-regression equation obtained by plotting the natural logarithm of isotopic enrichment against time. The time for each sample was taken as the midpoint of the sampling period. TBW was assumed to equal the $^{18}$O dilution space divided by 1.01 (13).

%BF from TBW was calculated assuming 73% hydration of the fat-free mass as follows:

$$\%BF = 100\left(\frac{\text{body weight} - (\text{TBW}/0.73)}{\text{body weight}}\right)$$

Selection for a similar range of obesity in each ethnic group means that any dependence of the factor of 73% on the degree of obesity should apply similarly to both groups.

**Statistical analysis**

Statistical analyses were performed by using SAS (version 6.04; SAS Institute Inc, Cary, NC). Student’s $t$ test was used to compare groups for selected variables. Bivariate correlations were assessed by using Pearson’s correlation coefficient. Residual analysis was used to check the assumptions of linear-regression analysis. Multiple-linear-regression analysis with the SAS STEPWISE procedure was used to develop prediction equations for %BF from height and girth measurements. Regression relations were compared for the two ethnic groups by using analysis of covariance. Agreement between methods of estimation of %BF were evaluated by using the analysis of Bland and Altman (14) in which the difference between the values is plotted against their mean. The 5% level was chosen for statistical significance. Results are expressed as means ± SDs.

**RESULTS**

There were no significant differences ($t$ test) between the two ethnic groups for any of the anthropometric variables measured except for the ratio of subscapular skinfold to triceps skinfold ($P < 0.0001$; Table 1). All measures except height were significantly correlated with %BF determined by isotope dilution.

For both the New Zealand European and Polynesian groups the relation between %BF by $^{18}$O dilution and BMI was curvilinear. Linear regression of %BF on the logarithm of BMI showed no evidence of nonlinearity for either group (Figure 1). No significant difference was found between the slopes of these regressions but covariance analysis showed their elevations to be significantly different ($P < 0.0001$). The common slope regression equation for predicting %BF from BMI was as follows:

$$\%BF = 72.66 \log_{10}(\text{BMI}) - 64.88 - 3.64 \text{ group } (\text{SEE} = 3.80\%, R^2 = 0.83)$$

where group is coded as 0 for New Zealand Europeans and 1 for Polynesians. Hence, for fixed BMI, Polynesians had lower %BF than New Zealand Europeans by 3.6%. At a BMI of 30 for the New Zealand Europeans the predicted %BF (42%) equates to a BMI of 34 for the Polynesians (Table 2). It can be seen from Table 2 that the 95% CIs for an individual prediction of %BF are rather wide but are quite narrow for a population mean (15). BMI was significantly correlated with height for the Polynesian group ($r = 0.40, P = 0.011$) but not for the New Zealand European group ($r = 0.06$).

The differences between %BF calculated from the Durnin and Womersley skinfold equations and %BF from isotope dilution are plotted in Figure 2 against the mean %BF by the two methods. The differences are negatively correlated with %BF ($r = -0.47, P = 0.002$ for New Zealand Europeans; $r = -0.39, P = 0.01$ for Polynesians). With increasing %BF the estimated fat from skinfold thicknesses progressively underes-
TABLE 1
Results of anthropometric measurements in 42 New Zealand European and 40 Polynesian women and correlations with percentage body fat from \( ^1 \)H dilution

<table>
<thead>
<tr>
<th></th>
<th>New Zealand Europeans</th>
<th>Polynesians</th>
<th>Correlation*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age (y)</td>
<td>22 ± 2 (18-27)²</td>
<td>22 ± 2 (18-25)</td>
</tr>
<tr>
<td></td>
<td>Height (m)</td>
<td>1.647 ± 0.063 (1.530-1.802)</td>
<td>1.664 ± 0.060 (1.534-1.782)</td>
</tr>
<tr>
<td></td>
<td>Weight (kg)</td>
<td>79.32 ± 22.72 (48.10-138.31)</td>
<td>85.79 ± 19.26 (56.20-131.71)</td>
</tr>
<tr>
<td></td>
<td>BMI (kg/m²)</td>
<td>29.2 ± 7.5 (16.4-48.0)</td>
<td>31.2 ± 7.9 (19.8-51.8)</td>
</tr>
<tr>
<td></td>
<td>Abdomen 1</td>
<td>82.5 ± 16.2 (61.7-115.4)</td>
<td>87.1 ± 14.8 (66.0-130.2)</td>
</tr>
<tr>
<td></td>
<td>Abdomen 2</td>
<td>94.1 ± 20.4 (66.3-148.5)</td>
<td>96.9 ± 17.2 (68.9-144.3)</td>
</tr>
<tr>
<td></td>
<td>Hip</td>
<td>108.5 ± 16.0 (85.1-159.5)</td>
<td>112.3 ± 14.8 (89.8-154.0)</td>
</tr>
<tr>
<td></td>
<td>Waist-hip</td>
<td>0.76 ± 0.07 (0.65-0.91)</td>
<td>0.77 ± 0.06 (0.70-0.93)</td>
</tr>
<tr>
<td></td>
<td>Skinfold thicknesses (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biceps</td>
<td>14.5 ± 8.2 (3.7-37.9)</td>
<td>12.8 ± 5.9 (4.2-26.0)</td>
</tr>
<tr>
<td></td>
<td>Triceps</td>
<td>29.3 ± 12.1 (10.3-52.1)</td>
<td>28.0 ± 9.4 (10.3-48.5)</td>
</tr>
<tr>
<td></td>
<td>Subscapular</td>
<td>26.4 ± 14.7 (7.8-59.1)</td>
<td>32.1 ± 13.8 (10.5-57.4)</td>
</tr>
<tr>
<td></td>
<td>Suprailiac</td>
<td>27.2 ± 15.8 (6.8-64.3)</td>
<td>29.4 ± 13.1 (7.2-60.5)</td>
</tr>
<tr>
<td></td>
<td>Subscapular: triceps</td>
<td>0.86 ± 0.24 (0.38-1.45)</td>
<td>1.13 ± 0.26 (0.64-1.77)</td>
</tr>
<tr>
<td></td>
<td>Body fat (%)</td>
<td>40.5 ± 9.9 (22.1-59.3)</td>
<td>39.1 ± 7.6 (26.0-54.0)</td>
</tr>
</tbody>
</table>

*Pearson correlation coefficients. All correlations were significant at \( P < 0.05 \) except for age and percentage body fat for Polynesians (P) and height and percentage body fat for New Zealand Europeans (N).

² \( r \pm SD; \) range in parentheses.

³ Waist = abdomen 1.

⁴ Significantly different from New Zealand Europeans, \( P < 0.0001 \) (two-sample independent \( t \)-test).

The estimated isotope-dilution result, possibly reflecting the difficulty of measuring skinfold thicknesses in obese subjects and the fact that subcutaneous fat deposits do not bear a constant relation to total fat with increasing obesity. The regression equations for %BF (isotope dilution) on %BF (skinfold equations) were linear for the two groups with similar slopes but significantly different elevations (Table 3).

The relation between %BF by isotope dilution and the sum of the four skinfold thicknesses (SSF) is shown in Figure 3. Residual analyses showed that the regressions for the prediction of %BF from SSF were linear. The slopes of these lines were not significantly different whereas the elevations were significantly different (\( P = 0.02 \)). The common slope regression equation for predicting %BF from SSF was as follows:

\[
%BF = 0.177 \text{SSF} + 23.25 - 2.28\text{g} \quad (\text{SEE} = 4.23\%, R^2 = 0.77), \quad (4)
\]

with group coded as 0 for New Zealand European and 1 for Polynesian.

The differences between %BF calculated from the Tran and Weltman girth equations and %BF from isotope dilution are plotted in Figure 4 against the mean %BF by the two methods. The differences are uncorrelated with %BF for the New Zealand European group (\( r = 0.15 \)) but positively correlated for the Polynesian group (\( r = 0.47, P = 0.002 \)). For the Polynesian subjects the girth equations tended to overestimate %BF at the higher values of %BF. The regression equations for %BF (isotope dilution) on %BF (girth equations) were linear for the two groups with similar slopes but significantly different elevations (Table 3).

The multiple-regression equations for predicting %BF (isotope dilution) from height and girth measurements were as follows:
TABLE 2
Predicted percentage body fat (%BF) by isotope dilution at equivalent BMI values for 42 New Zealand European and 40 Polynesian women

<table>
<thead>
<tr>
<th>BMI (kg/m²)</th>
<th>New Zealand European</th>
<th></th>
<th></th>
<th>Polynesian</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%BF</td>
<td>95% CI for individual</td>
<td>95% CI for mean</td>
<td>%BF</td>
<td>95% CI for individual</td>
<td>95% CI for mean</td>
</tr>
<tr>
<td>15</td>
<td>20.6</td>
<td>12.6, 28.5</td>
<td>18.2, 22.9</td>
<td>16.9</td>
<td>9.0, 24.8</td>
<td>14.4, 19.5</td>
</tr>
<tr>
<td>20</td>
<td>29.7</td>
<td>22.0, 37.3</td>
<td>28.1, 31.2</td>
<td>26.0</td>
<td>18.3, 33.7</td>
<td>24.3, 27.7</td>
</tr>
<tr>
<td>25</td>
<td>36.7</td>
<td>29.1, 44.3</td>
<td>35.7, 37.6</td>
<td>33.1</td>
<td>25.4, 40.7</td>
<td>31.9, 34.2</td>
</tr>
<tr>
<td>30</td>
<td>42.4</td>
<td>34.8, 50.1</td>
<td>41.6, 43.3</td>
<td>38.8</td>
<td>31.2, 46.4</td>
<td>38.0, 39.6</td>
</tr>
<tr>
<td>35</td>
<td>47.3</td>
<td>39.7, 54.9</td>
<td>46.3, 48.3</td>
<td>43.7</td>
<td>36.1, 51.3</td>
<td>42.8, 44.6</td>
</tr>
<tr>
<td>40</td>
<td>51.5</td>
<td>43.8, 59.2</td>
<td>50.2, 52.9</td>
<td>47.9</td>
<td>40.2, 55.5</td>
<td>46.7, 49.1</td>
</tr>
</tbody>
</table>

1 95% CIs are shown for an individual prediction and for a mean value (15).

New Zealand Europeans:

\%
BF = 0.313 abdomen + 0.246 hip − 0.313 height + 37.62 (SEE = 3.83%, \( R^2 = 0.86 \)) (5)

Polynesians:

\%
BF = 0.188 abdomen + 0.265 hip − 7.916 (SEE = 3.40%, \( R^2 = 0.81 \)) (6)

where abdomen is the average of abdomen 1 and abdomen 2. Height was not a significant predictor for the Polynesian group. No evidence of curvilinearity was seen in the relations between %BF and either girth measurement.

The ratio of subcapular to triceps skinfold thicknesses was more strongly correlated with %BF for the New Zealand Europeans \((r = 0.54, P = 0.0002)\) than for the Polynesians \((r = 0.43, P = 0.006)\). We divided the groups into obese and nonobese on the basis of BMI ≥ 30 for obese New Zealand Europeans \((n = 20)\) and BMI ≥ 34 for obese Polynesians \((n = 10)\). The higher BMI threshold for Polynesians is suggested by the regression relation found above. This ratio was significantly higher in the obese than in the nonobese New Zealand Europeans \((0.99 ± 0.21 \text{ compared with } 0.74 ± 0.21, \ P = 0.0003)\) whereas in the Polynesian group there was no significant difference between the obese and nonobese subgroups \((1.27 ± 0.22 \text{ compared with } 1.08 ± 0.28, \ P = 0.07)\).

DISCUSSION

Anthropometric methods, particularly the use of BMI, have received wide attention for the assessment of body fat and obesity. Their low cost and simplicity make them attractive for epidemiologic purposes (16). A large number of equations for predicting body composition with these methods are available in the literature (17–19). These equations have been developed in predominantly white populations and the appropriateness of their use in nonwhite groups has been questioned (20). In the present study we examined in both a New Zealand European and Polynesian population of young women the relations between %BF derived from TBW measurements and BMI, skinfold thicknesses at four sites, and abdominal and hip girth measurements. We found significant ethnicity effects in all these relations.

It is perhaps not surprising that the generalized skinfold equations of Durnin and Womersley (8) and the generalized girth equations of Tran and Weltman (9) yielded significantly different results for the two ethnic groups because these equations were developed in white populations. It has been reported that Polynesian women resident in Auckland, New Zealand, have a higher bone density than New Zealand European women (21), a result also found in American blacks (22). The influence of higher bone density on the density of the fat-free mass would be expected to lead to underestimation of fat in the conversion of density to %BF by the Brozek equation (7). Ethnicity-related differences in fat distribution (23), relative sitting height, and muscle mass that have been reported (17) will also be important influences on the differences we have seen. We found a marked difference in the ratio of subcapular to triceps skinfold thickness between the two ethnic groups. This ratio is a measure of the distribution of subcutaneous fat between the peripheral and central regions. With increasing %BF the New Zealand Europeans appeared to deposit more central fat whereas in the Polynesians the fat stores were distributed in a similar way for high and low %BF. The results indicate more central subcutaneous fat and less peripheral fat in the Polynesian group (particularly at lower %BF).
TABLE 3
Relation between percentage body fat (%BF) estimates by $^{18}$O dilution and predicted by skinfold thickness or girth measurements for 42 New Zealand European and 40 Polynesian women.

<table>
<thead>
<tr>
<th>Measurements by group</th>
<th>$a$</th>
<th>$b$</th>
<th>$r^2$</th>
<th>SEE (BF%)</th>
<th>Test for heterogeneity of slopes</th>
<th>Covariance analysis $^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Skinfold thicknesses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Zealand European</td>
<td>0.62</td>
<td>1.13</td>
<td>0.84</td>
<td>3.98</td>
<td>0.60</td>
<td>0.0009</td>
</tr>
<tr>
<td>Polynesian</td>
<td>0.08</td>
<td>1.06</td>
<td>0.72</td>
<td>4.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Girths</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Zealand European</td>
<td>7.55</td>
<td>0.88</td>
<td>0.87</td>
<td>3.65</td>
<td>0.058</td>
<td>0.0001</td>
</tr>
<tr>
<td>Polynesian</td>
<td>9.95</td>
<td>0.73</td>
<td>0.83</td>
<td>3.16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$ $a$, intercept of the linear regression of %BF by $^{18}$O on %BF by anthropometric measurements; $b$, slope of the linear regression of %BF by $^{18}$O on %BF by anthropometric measurements; $r^2$, explained variance.

$^2$ Test for difference in elevations of the regression lines.

$^3,5$ Significantly different from 0: $^3 P < 0.001$, $^5 P < 0.0001$.

$^4,6$ Significantly different from 1: $^4 P < 0.05$, $^6 P < 0.0001$.

These results have implications for the establishment of suitable thresholds for obesity in the Polynesian population, as has been done for whites. The most commonly used measure of obesity is BMI, with 20–25 being categorized as normal and a value > 30 as obese (4–6). We found that at a fixed %BF, BMI in Polynesians was three to four units higher than in New Zealand Europeans. A BMI ≤ 30 may be considered normal in Polynesian women as suggested by others (BA Swinburn, personal communication, 1994). This means that population surveys in New Zealand should take account of ethnicity in the interpretation of statistics. The Hillary Commission survey in 1989 measured 3400 New Zealanders aged ≥ 15 y (24, 25). The ethnic mix of these subjects was not reported and no allowance was made for ethnic differences in the reporting of the data and associated health risks. Maori data were reported separately (26) but Pacific Island and Asian data were not presented. Asians have a lower BMI but higher %BF than whites (27). Note that in contrast with New Zealand Europeans, we found that BMI was significantly negatively correlated with height in the Polynesian group so that this index may have only marginal usefulness in this ethnic group.

In our hands, skinfold-thickness measurements were more difficult, more uncomfortable for the subjects, and less repeatable than girth measurements and took longer to obtain. Girth measures correlated better with percentage body fat than did skinfold estimations, suggesting that they may be a better index of weight loss or gain than repeat skinfold measurements. Although skinfold thicknesses are a measure of subcutaneous fat only, girth measurements include, with lean tissue, viscerally and subcutaneously deposited fat. %BF is a useful health index because it correlates with BMI and mortality and morbidity for whites (4). The correlation of

**FIGURE 3.** Relation between percentage body fat (%BF) by $^{18}$O dilution and the sum of four skinfold thicknesses (ΣSF) for 42 New Zealand European (○) and 40 Polynesian (●) women. The linear regressions are %BF = 0.19 ΣSF - 22.3 (SEE = 4.4%, $r^2 = 0.81$) for the New Zealand Europeans (dashed line) and %BF = 0.16 ΣSF - 22.5 (SEE = 4.0%, $r^2 = 0.72$) for the Polynesians (solid line).

**FIGURE 4.** Mean differences between percentage body fat estimated by the girth equations of Tran and Weltman (9) (%BF(girths)) and derived from $^{18}$O dilution measurements (%BF($^{18}$O)) plotted against the mean of the two methods for 42 New Zealand European (○) and 40 Polynesian (●) women. (Dotted line, New Zealand Europeans; dashed line, Polynesians).
%BF or other adiposity measures in Polynesians needs to be determined and considered in the formulation of what is considered normal or low risk. We confirmed that various anthropometric measurements of %BF derived for white women are not applicable to Polynesian women without modification. This investigation needs to be extended to younger and older females and to males. Criteria for assessment of fatness in population surveys should use equations derived specifically for the ethnic group being studied. The correlation of body fat with other risk factors and morbidity and mortality needs to be explored further in the Polynesian population.

REFERENCES