Optimized predictions of absolute and relative amounts of body fat from weight, height, other anthropometric predictors, and age

Ingrid Larsson, Björn Henning, Anna Karin Lindroos, Ingmar Näslund, Carl David Sjöström, and Lars Sjöström

ABSTRACT

Background: Body mass index (BMI) is the dominating weight-for-height index, but its validity as a body fat (BF) index has not been properly examined.

Objectives: Our aims were to establish and validate optimal weight-for-height indexes for predicting absolute and relative (percentage) amounts of BF, to examine whether other commonly available anthropometric variables or age could add to the predictive power, and to explore the upper limit for percentage BF.

Design: One thousand and one hundred twelve randomly selected subjects, and an additional 149 obese subjects, were included in the study. The subjects were randomly allocated to either a primary study group or a validation group. BF was measured with dual-energy X-ray absorptiometry. The relations between weight/height\(^x\) (W/H\(^x\)) and BF (absolute or percentage) were examined for values of the exponent \(x\) that ranged from 0.0 to 3.0. The predictive power of equations that were based on optimal weight-for-height indexes was compared with equations based on weight, height, other anthropometric variables, and age.

Results: Absolute BF was optimally and linearly predicted by W/H\(^1\), whereas the percentage BF was optimally and nonlinearly predicted by W/H\(^2\). The percentage BF asymptotically approached 52% in women and 56% in men. The percentage BF increased only marginally from BMI (in kg/m\(^2\)) values of >35 in women and >60 in men. Predictions of absolute BF were associated with smaller errors (8.5% for men and 5.7% for women) than were predictions of percentage BF (8.7% for men and 7.9% for women). The addition of other anthropometric measurements for both men and women, and the addition of age for women only, in the regression analyses moderately reduced these errors.

Conclusion: Our data suggest that W/H may be a more optimal weight-for-height index than is BMI, particularly at high body weights. Am J Clin Nutr 2006;83:252–9.

KEY WORDS Body fat indexes, maximum relative fatness, prediction of body fat, weight-for-height

INTRODUCTION

By 1835, the Belgian mathematician Lambert Adolphe Jacques Quetelet observed that the weight of normal adults was proportional to their height squared; ie, that weight/height\(^2\) (W/H\(^2\)) was constant for people of normal build (1). Today, Quetelet’s index is better known as the body mass index (BMI), which is the most widely used measure to describe degrees of underweight and overweight in the literature. Compelling reasons must thus be provided for proposing an alternative weight-for-height index.

Benn (2) suggested that the exponent (\(p\)) of height should be chosen in such a way that W/H\(^p\) results in a correlation with height of zero. However, Benn never examined the correlation between measured body fat (BF) and height (2), and study groups with positive and negative correlations between height and BF have been reported (3).

BMI has been used both as a risk index and as a body fat index (4, 5). The exponent of height will not necessarily be the same in an optimal risk index as in an optimal body fat index that is based on weight-for-height. Also, the exponent of height in an optimal risk index may be different in different study groups and for different endpoints (3, 6).

In the present study, we focus on weight-for-height indexes as BF indicators. BMI is usually used as an indicator of percentage BF (7), but sometimes it is used as an index of the absolute amount of BF (8). The optimal exponent of height may be different when estimating percentage and absolute BF, but this has not been properly examined. Furthermore, it is obvious that the human body cannot contain 100% fat. The relation between percentage BF and any weight-for-height index must thus be curvilinear. The level at which the percentage BF asymptotically approaches an upper maximal percentage of body weight has not previously been examined. At a given body weight, height is negatively related to BF. This cannot be reflected by BMI or other weight-for-height ratios, and, therefore, an examination into whether BF is better predicted by weight, height, other anthropometric measurements, and age as separate independent variables seems warranted. For the reasons outlined above, our aims were to examine the following in a randomly selected sample of persons, which had an added number of obese persons: 1) to establish optimal weight-for-height indexes for the prediction of absolute and percentage BF in men and women; 2) to examine...
if multivariate equations based on weight, height, and other anthropometric variables can predict BF with higher precision than the optimal weight-for-height index; and 3) to examine if the percentage BF asymptotically approaches an upper maximal value.

SUBJECTS AND METHODS

Subjects

One hundred forty-nine obese persons from 2 Swedish cities (Mölndal and Örebro) who were part of the Xenical for the prevention of of diabetes in obese study (XENDOS; 9) were added to a randomly selected sample of persons (n = 1112) from the general population from the same 2 cities (10). Thus, a total of 1261 subjects (548 men and 713 women) were examined. All subjects were white, except for 4 women of Asian origin. Participation rates were 53.7% for the men and 57.6% for the women in the population-based sample. A nonparticipation analysis indicated similar characteristics between participants and nonparticipants (10).

The men and women in the total sample were each randomly allocated to either a primary study group or a validation group. The primary study groups were used for developing optimal weight-for-height indexes and anthropometric equations for predicting absolute BF (in kg) and percentage BF. These indexes and equations were then tested in the validation groups.

The Ethics Review Boards at Göteborg and Örebro University hospitals approved all examinations of the randomly selected subjects. Similarly, the examinations of the obese subjects [ie, the baseline examination of the XENDOS subgroup (9)] were approved by the same boards. Informed consent was obtained from all subjects before the examinations.

Anthropometric measurements

After an overnight fast, the subjects’ anthropometric measurements were taken while they were dressed in underwear. The subjects’ height was measured to the nearest 0.01 m while the subjects were standing barefoot with their backs to a wall-mounted stadiometer. The subjects’ weight was measured to the nearest 0.1 kg with calibrated scales.

Two trunk circumferences were measured while the subjects were in a recumbent position. The waist circumference was measured in cm at the end of a normal expiration at the point midway between the most caudal part of the lateral costal arch and the iliac crest. The hip circumference was measured in cm at the level of the iliac crest. The sagittal trunk diameter was the distance from the examination table up to the horizontal level as measured with the ruler (11).

Dual-energy X-ray absorptiometry

Body composition was assessed with dual-energy X-ray absorptiometry (DXA), which results in a 3-compartment model that consists of BF, lean tissue mass (LTM), and bone mineral content (BMC) (12). The 2 DXA scanners used for the Mölndal and Örebro samples were LUNAR DPX-L machines (LUNAR Radiation, Madison WI) with identical software (version 1.31) and with the extended analysis program for total body analysis (13). The LUNAR DPX-L scanner uses a constant potential X-ray source and a K-edge filter to achieve a congruent beam of stable dual-energy radiation. A quality assurance test was conducted on a daily basis, as recommended by the manufacturer. According to the manufacturer recommendations, persons with body weights ≤35 or ≥120 kg cannot be reliably examined with the DPX-L scanner (13). None of the subjects weighed <43 kg. In the present study, the upper body weight limit was 110.0 kg.

The precision of our Mölndal scanner was estimated in a comparison of 2 separate examinations of 10 healthy, nonobese subjects. The within-subject CVs were 1.7% for BF, 0.7% for LTM, 1.9% for BMC, and 1.5% for bone mineral density (BMD). The precision was also examined in 50 obese subjects who were measured twice on the 2 DXA scanners. The within-subject CVs for the machine used in the Mölndal sample were 1.6% for BF, 0.7% for LTM, 0.9% for BMC, and 0.8% for BMD. The within-subject CVs for the Örebro machine were 1.4% for BF, 1.0% for LTM, 1.4% for BMC, and 0.6% for BMD.

Statistics

Age, anthropometric measurements, and DXA-measured body components are presented as means (±SDs). Equations obtained from the primary study groups were tested in the validation groups, and errors between the measured and predicted BF were calculated as the within-subject CVs.

To establish optimal weight-for-height indexes, correlation coefficients (r) for measured BF (absolute or percentage) compared with WHt were plotted against the exponent of height (γ), where x ranged from 0.0 to 3.0. Measured BF (absolute or percentage) was regressed by the optimal power type indexes in the primary study groups, and the resulting equations were used to predict absolute or percentage BF in the validation groups. Differences in absolute residuals and in absolute changes between the measured and predicted BF, as obtained by the equations, were tested with paired t tests.

In the primary groups, multiple regression analyses were performed to develop anthropometry-based multivariate equations predicting absolute BF. Body height, weight, waist and hip circumferences, sagittal diameter, and age were included in the regression model. Backward elimination of the variables was then undertaken until all remaining terms in the equation were significant. Finally, the equations were refined by examining whether any previously removed variable could be added back into the model with a maintained significance.

To predict percentage BF from BMI (or other power-type weight-height indexes), nonlinear least-square fits were performed with the use of an exponential equation in the primary study groups. The best fits of percentage BF (γ) were achieved by adjusting 3 coefficients, which represented the asymptote; ie, y value at high BMIs (a), the BMI at 0% BF (x0), and the “bending” of the curve (b) in the equation:

\[
y = a \times \left(1 - e^{-b(x - x_0)}\right)
\]  

(1)

To illustrate the parameters (a) and (x0), the nonlinear curves were extrapolated outside the range of observations.

All tests were two-tailed. The statistical analyses and the random allocation of subjects to primary and validation groups were conducted with JMP statistical software package, version 5.1.1.
TABLE 1
Age, anthropometric measures, and dual energy X-ray absorptiometry–measured body composition in the primary and validation groups.

<table>
<thead>
<tr>
<th></th>
<th>Primary group</th>
<th>Validation group</th>
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<tbody>
<tr>
<td></td>
<td>(n = 274)</td>
<td>(n = 274)</td>
</tr>
<tr>
<td></td>
<td>(n = 357)</td>
<td>(n = 356)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>48.9 ± 7.2</td>
<td>49.9 ± 7.1</td>
</tr>
<tr>
<td></td>
<td>(31.0–61.8)</td>
<td>(31.0–61.4)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.78 ± 0.07</td>
<td>1.79 ± 0.06</td>
</tr>
<tr>
<td></td>
<td>(1.56–2.01)</td>
<td>(1.61–1.95)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>83.6 ± 12.4</td>
<td>83.8 ± 10.9</td>
</tr>
<tr>
<td></td>
<td>(52.4–110.0)</td>
<td>(53.2–109.4)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>26.2 ± 3.9</td>
<td>26.1 ± 3.4</td>
</tr>
<tr>
<td></td>
<td>(17.9–38.3)</td>
<td>(18.4–36.2)</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>93.2 ± 10.7</td>
<td>93.6 ± 9.4</td>
</tr>
<tr>
<td></td>
<td>(69–120)</td>
<td>(72–125)</td>
</tr>
<tr>
<td>Hip circumference (cm)</td>
<td>99.5 ± 6.5</td>
<td>100.0 ± 6.1</td>
</tr>
<tr>
<td></td>
<td>(81–122)</td>
<td>(82–117)</td>
</tr>
<tr>
<td>Sagittal diameter (cm)</td>
<td>21.4 ± 3.1</td>
<td>21.3 ± 2.8</td>
</tr>
<tr>
<td></td>
<td>(15–31)</td>
<td>(14–30)</td>
</tr>
<tr>
<td>Lean tissue mass (kg)</td>
<td>58.5 ± 6.2</td>
<td>59.5 ± 5.6</td>
</tr>
<tr>
<td></td>
<td>(39.7–76.2)</td>
<td>(43.1–72.5)</td>
</tr>
<tr>
<td>Body fat (kg)</td>
<td>21.6 ± 8.3</td>
<td>21.0 ± 7.2</td>
</tr>
<tr>
<td></td>
<td>(4.1–45.1)</td>
<td>(6.0–41.3)</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>25.1 ± 6.7</td>
<td>24.5 ± 6.0</td>
</tr>
<tr>
<td></td>
<td>(7.0–42.4)</td>
<td>(10.0–40.3)</td>
</tr>
<tr>
<td>Bone mineral content (kg)</td>
<td>3.2 ± 0.4</td>
<td>3.2 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>(2.1–4.7)</td>
<td>(1.6–4.4)</td>
</tr>
</tbody>
</table>

All values are x ± SD; range in parentheses. Within each sex, no statistically significant differences between the primary and validation groups were observed (t test). Between the sexes, no statistically significant differences were observed for age and BMI (t test). All other variables were significantly different between the sexes (P < 0.01 for all) in both the primary and validation groups.

RESULTS
Sample characteristics
The age, anthropometric measures, and DXA-measured body compositions for the primary groups and the validation groups are shown in Table 1. No statistically significant differences were observed between the primary group and the validation group, either for the men or women. In both the primary and validation groups, the men and women were of similar age and had similar BMIs. Compared with the men, the women were shorter, had lower body weights, waist circumferences, sagittal trunk diameters, lean tissue masses, and bone mineral contents and higher hip circumferences and absolute and percentage BF (P < 0.01 for all) (Table 1).

Optimal weight-for-height indexes
The optimal weight-for-height index for the prediction of absolute BF was close to W/H1.0 in both the men (optimal exponent of height 1.1) and the women (optimal exponent 0.9) in the primary study groups (Figure 1). W/H seemed to be more closely correlated with BF in the women (rmax = 0.97) than in the men (rmax = 0.91).

In contrast, the percentage BF was more optimally predicted by weight-for-height indexes close to BMI (W/H1.8 for men and W/H1.9 for women). The optimal correlation coefficients were lower for the prediction of percentage BF (rmax = 0.78 for men and 0.85 for women) than for the prediction of absolute BF.

The DXA-measured absolute BF in the primary group was regressed by either W/H or W/H² in both the men and women (Figure 2). Compared with W/H², W/H resulted in higher r values and significantly lower mean absolute residuals (2.8 compared with 3.1 kg in the men, P = 0.003; 2.1 compared with 2.5 kg in the women).
kg in the women, \( P < 0.001 \). In the women, the relation between absolute BF and BMI was nonlinear (ie, BMI\(^2\) contributed significantly to the explained variance). The linear relations between absolute BF and W/H are described by the equations:

\[
\text{Men: BF (kg)} = 30.84 + 1.120 \times \text{W/H} \\
\text{Women: BF (kg)} = 24.18 + 1.181 \times \text{W/H} \\
\]

\( r = 0.97, 2.1 \pm 1.8 \text{ kg*} \)

\[\text{W/H}^{0.0}\]

\( r = 0.96, 2.5 \pm 2.1 \text{ kg*} \)

**FIGURE 2.** Linear regression analysis between dual-energy X-ray absorptiometry (DXA)–measured body fat (BF\(_{\text{DXA}}\) in kg) and weight/height (W/H) or W/H\(^2\) in 274 men (A and B) and in 357 women (C and D) from the primary group. Values are the \( \bar{x} \) (±SD) of absolute residuals. Paired \( t \) tests showed that lower absolute residuals were obtained with the use of W/H rather than W/H\(^2\), both in men (\( P = 0.003 \)) and in women (\( P < 0.001 \)). The following equations were obtained:

A: BF\(_{\text{DXA}}\) (kg) = −30.84 + 1.120 \times \text{W/H};
B: BF\(_{\text{DXA}}\) (kg) = −28.17 + 1.895 \times \text{W/H}\(^2\);
C: BF\(_{\text{DXA}}\) (kg) = −24.18 + 1.181 \times \text{W/H}; and D: BF\(_{\text{DXA}}\) (kg) = −49.47 + 3.865 \times \text{W/H}^{0.0} − 0.03443(\text{W/H})\(^2\).

**Measured absolute body fat compared with body fat predicted from weight-for-height indexes**

The 4 equations of Figure 2 were used to predict BF in the validation groups (Figure 3). In a plot of measured versus predicted absolute BF, the intercepts were close to zero and regression coefficients close to 1.0 (Figure 3). However, the absolute differences between the measured and predicted absolute BF were significantly lower (\( P < 0.01 \)) when W/H rather than BMI was used in the predictive equations, and the corresponding errors were lower (8.5% compared with 9.4% for men and 5.7% compared with 6.8% for women) (Figure 3).

**Univariate and multivariate prediction of absolute body fat**

In the men in the primary study group, \( R^2 \) values for absolute BF compared with selected single variables were 0.86 for waist circumference, 0.82 for W/H, 0.78 for W/H\(^2\), 0.76 for weight, and 0.00 for height. In the women, the corresponding values were 0.94, 0.92, 0.91, 0.86, and 0.01. The same rankings and similar \( R^2 \) values were observed in the validation group.

Next, we examined if the predictions of absolute BF that were based on W/H could be improved in the primary study group by using weight and height separately and by adding age and additional anthropometric measurements (waist circumference, hip circumference, and sagittal trunk diameter) to the regression analysis (Table 2).

In the men, a regression analysis with backward elimination (see Statistics) resulted in 3 significant predictors: weight, height, and waist circumference. Compared with the equation based on W/H, this equation resulted in significantly lower absolute residuals and higher explained variances (Table 2, upper part). In the women, weight, height, waist circumference, hip circumference, and age all remained significant after backward elimination, and the corresponding equation resulted in lower absolute residuals than did the equation based on W/H (absolute BF: 1.8 compared with 2.1 kg; \( P < 0.001 \)). An equation based only on weight, height, and waist circumference also resulted in lower absolute residuals in the women in the primary study group (absolute BF: 2.0 compared with 2.1 kg; \( P < 0.001 \)) (Table 2, upper part).

The anthropometric, multivariate equations that were developed in the primary study group were used to estimate absolute BF in the validation group (Table 2, lower part). In the men, the equation based on weight, height, and waist circumference...
resulted in significantly lower absolute differences between the measured and estimated absolute BF than did the equation based on W/H (absolute BF: 2.3 compared with 2.6 kg; \( P < 0.02 \)). The corresponding percentage errors were 7.7% and 8.5%. In the women, the complete anthropometric equation reduced the absolute differences, whereas the equation based on weight, height, and waist circumference did not (Table 2, lower part).

**Nonlinear relations between percentage body fat and weight-for-height indexes**

As illustrated in Figure 1, weight-for-height indexes close to BMI seem to be optimal for predicting the percentage BF. The nonlinear relations between percentage BF and W/H\(^2\) in the men and women in the primary study group, when analyzed with an exponential model, are shown in Figure 4. In the women (Figure 4B), BF asymptotically approached 51.6% (95% CI: 49.4%, 53.9%) of body weight. Interestingly, similar asymptotic values were obtained when the percentage BF was regressed by weight (58.3%), W/H (54.6%), and W/H\(^3\) (53.7%). In the men, the percentage BF increased only marginally at BMI values > 60. With the same exponential function, 0% body fat was achieved at a BMI of 13.1 in the men (Figure 4A) and 13.5 kg/m\(^2\) in the women (Figure 4B).

The exponential equations of Figures 4A and 4B were used to predict the percentage BF in the validation group (Figures 4C and 4D). The absolute difference between the measured percentage BF and the percentage BF that was predicted from the exponential equations was \( \approx 3\% \) for both the men and women. The corresponding CVs were 8.7% for the men and 7.9% for the women.

**DISCUSSION**

The optimal exponent \( x \) of height in the equation W/H\(^x\) was 1.1 in the men and 0.9 in the women when estimating the absolute amount of BF from weight-for-height indexes in our study groups. When estimating the percentage BF, the optimal exponents were 1.8 and 1.9, respectively. However, the change in predictive power by approximating these exponents to 1.0 and 2.0, respectively, was marginal (flat top of curves in Figure 1). We therefore recommend W/H when predicting the absolute amount of BF and BMI when predicting the percentage BF. The relation between W/H and absolute BF was linear, whereas the one between BMI and the percentage BF was nonlinear.
TABLE 2

Body fat (in kg) measured by dual-energy X-ray absorptiometry (BFDXA) and predicted (BFpred) from height, weight, waist and hip circumferences, age, and weight/height (W/H) in men and women.

<table>
<thead>
<tr>
<th>Primary group</th>
<th>R²</th>
<th>CV (%)</th>
<th>x ± SD (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Men (n = 271)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) BFDXA = 18.38 - 13.49 × height + 0.2572 × weight + 0.4567 × waist</td>
<td>0.88</td>
<td>—</td>
<td>2.1 ± 1.7</td>
</tr>
<tr>
<td>2) BFDXA = -30.84 + 1.120 × W/H</td>
<td>0.82</td>
<td>—</td>
<td>2.8 ± 2.1</td>
</tr>
<tr>
<td><strong>Women (n = 357)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) BFDXA = 15.20 - 25.69 × height + 0.6276 × weight + 0.1069 × waist</td>
<td>0.95</td>
<td>—</td>
<td>2.0 ± 1.7</td>
</tr>
<tr>
<td>4) BFDXA = 0.1966 - 23.35 × height + 0.560 × weight + 0.0903 × waist + 0.1489 × hip + 0.453 × age</td>
<td>0.95</td>
<td>—</td>
<td>1.8 ± 1.6</td>
</tr>
<tr>
<td>5) BFDXA = -24.18 + 1.181 × W/H</td>
<td>0.94</td>
<td>—</td>
<td>2.1 ± 1.8</td>
</tr>
<tr>
<td><strong>Validation group</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6) BFDXA Versus BFpred from height, weight, waist (Equation 1)</td>
<td>0.84</td>
<td>7.7</td>
<td>2.3 ± 1.8</td>
</tr>
<tr>
<td>7) BFDXA versus BFpred from W/H (Equation 2)</td>
<td>0.80</td>
<td>8.5</td>
<td>2.6 ± 1.8</td>
</tr>
<tr>
<td><strong>Men (n = 274)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8) BFDXA Versus BFpred from height, weight, waist (Equation 3)</td>
<td>0.93</td>
<td>5.6</td>
<td>2.1 ± 1.8</td>
</tr>
<tr>
<td>9) BFDXA versus BFpred from height, weight, waist, hip, age (Equation 4)</td>
<td>0.94</td>
<td>5.4</td>
<td>2.0 ± 1.8</td>
</tr>
<tr>
<td>10) BFDXA kg versus BFpred from W/H (Equation 5)</td>
<td>0.93</td>
<td>5.7</td>
<td>2.2 ± 1.8</td>
</tr>
</tbody>
</table>

1. The equations were constructed in the primary groups of men and women from measured body fat (BFDXA) with multiple regression analysis with backward elimination. The derived equations were tested in the validation groups. Waist, waist circumference (in cm); hip, hip circumference (in cm; Equations 2 and 5 are from Figures 2A and 2C, respectively. Data in Equations 7 and 10 are from Figures 3A and 3C, respectively.

2. Within subset CV between measured and predicted body fat.

3. For the primary group, the values are the x ± SD of absolute residuals; for the validation group, the values are the x ± SD of the absolute difference between measured and predicted body fat.

4. Significantly different from Equation 1, P < 0.001 (paired t test).

5. Significantly different from Equations 3 and 4, P < 0.001 (paired t test).

6. Significantly different from Equation 6, P = 0.02 (paired t test).

7. Not significantly different from Equation 10, P = 0.33 (paired t test).

8. Significantly different from Equation 10, P = 0.002 (paired t test).

Several publications have specified criteria for an optimal obesity index (2, 5, 14–19). Some of the suggested criteria are the following: 1) the index should be highly correlated with body weight, 2) the index should be highly correlated with body fat expressed in absolute terms or as a percentage, and 3) the index should have as low a correlation as possible with height. The first criterion is correct, but insufficient. Several studies have tested weight-for-height indexes only in relation to weight (15, 16, 20), and evidently such procedures are not sufficient for establishing an optimal BF index. The second criterion is correct, and weight-for-height indexes have been correlated with skinfold-thickness (21) or with both absolute and percentage BF, as measured with underwater weighing (22–24). Several studies have suggested that percentage BF is optimally related to BMI (14, 18, 19, 22, 25), which agrees with our study. However, it has also been claimed that absolute BF is optimally predicted by BMI (8, 22), which clearly contrasts with our findings. Garrow and Webster (8) claimed that BMI was the optimal weight-for-height index for predicting BF mass because BF/H² was closely related to WH² (r = 0.943). Evidently, the same denominator in both expressions may contribute to the high correlation. The last criterion, which was suggested by Benn (2), can be questioned because the correlation coefficients between height and BF can range from negative to positive values depending on the study groups examined (3). Thus, it seems reasonable that weight-for-height indexes should ideally be related to height in the same way as measured BF (3).

The percentage BF was nonlinearly related to BMI and other weight-for-height indexes. In the clinic, the percentage BF is intuitively considered to be proportionally related to BMI. Although this is approximately true in the normal BMI range, the percentage BF was only marginally increased between high and very high BMIs. Our exponential model indicated that the relative amount of BF may not exceed 50–60%. With the same model, a 0% BF was estimated to occur at a BMI of approximately 28.0% BF in 312 men and from 34.0% to 37.7% BF in 394 women. We agree with Gallagher et al (24) that this represents a significant criterion. The second criterion is correct, but insufficient. Several studies have tested
cardiovascular disease risk factors (27) and to hard endpoints (ie, deaths) (28), whether BMI is an optimal risk index remains in question. For instance, in a previous congress report, we found that myocardial infarction was optimally predicted by W/H^4.8 in 1462 women, whereas W/H^2.2 predicted myocardial infarction optimally in men in 2 separate study groups (n = 1155 and n = 10,004) (3). Optimal risk indexes need to be additionally evaluated in separate studies, particularly because the exponent of height (x) influences the ranking of persons by weight-for-height.

The present study was limited in some respects. Only persons aged 30–61 y were examined. Due to limitations of the DXA technology, subjects with body weights >110 kg were excluded. Therefore, our statements are correct only to the extent that DXA is a valid technique. The subjects were mainly white, and our optimal indexes and equations were based on study groups of limited size (274 men and 357 women). On the other hand, most of our study subjects were randomly selected, and we validated our results in separate, but equally large, study groups. Although similar procedures have been used in other studies (26), independent validations of weight-for-height indexes and BF equations are unusual (29).

In conclusion, the present study showed that absolute BF was best predicted by W/H, whereas the percentage BF was optimally predicted by W/H^2. The relative amount of BF did not seem to exceed 50–60% of body weight. Although BMI was approximately proportional to the percentage BF in the normal-weight range, this was not the case in severely obese subjects. In contrast, W/H was linearly related to the absolute amount of BF over the examined weight ranges. These circumstances, as well as the fact that absolute BF was predicted with a greater precision than was percentage BF, suggest that W/H may be a more optimal weight-for-height index than BMI, particularly at high body weights.

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IL, CDS, and LS contributed to the study design. IL, BH, and LS contributed to the data analysis. IL, AKL, IN, and LS were responsible for different parts of data collection. All authors contributed to the manuscript writing. None of the authors had any conflicts of interest.

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